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ABSTRACT

This document features the experiences of three science teachers who video and audiotaped classroom proceedings in order to go back over what was said in classroom events, to explore the intentions and ideas that were perhaps not fully understood at the time. Mary DiSchino, who teaches 3rd and 4th graders, teaches a science curriculum which she organizes around questions her students ask about the world. She tells the story of her students' investigation of one question, "Why do bees sting and why do they die afterwards?" Laura Sylvan has searched for ways to introduce "authentic" discussion into her 7th and 8th grade science classroom, discussion in which students are both respectful and genuinely engaged. She presents two discussions which she felt were particularly fruitful and explores what the students were saying and what she learned about them from their talk. Chris Whitbeck, who teaches middle-school science, describes an investigation he did with four students from his class on how bicycles work; he explores the deeper view he gained on how the students thought about bicycles and on what experiences influenced their thinking. (AA)

Teachers' Perspectives on Children's Talk in Science

by Mary DiSchino
Laura Sylvan
and Christopher Whitbeck

TERC

Working Papers

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with an introduction by Cynthia Ballenger

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Preface

TERC is a nonprofit education research and development organization founded in 1965 and committed to improving science and mathematics learning and teaching. Our work includes research from both cognitive and sociocultural perspectives, creation of curriculum, technology innovation, and teacher development. Through our research we strive to deepen knowledge of how students and teachers construct their understanding of science and mathematics.

Much of the thinking and questioning that informs TERC research is eventually integrated in the curricula and technologies we create and in the development work we engage in collaboratively with teachers. In 1992 we launched the TERC Working Papers series to expand our reach to the community of researchers and educators engaged in similar endeavors.

The TERC Working Paper series consists of completed research, both published and unpublished, and work-in-progress in the learning and teaching of science and mathematics.

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Introduction

Eleanor Duckworth (1987) suggests that a good curriculum should not be a plan or a series of activities that determines all the "best" instructional moves; such a view of curriculum constrains a teacher's thinking and limits his or her experience with the domain and the students. Rather, the goal of a curriculum should be to support teachers, to scaffold their efforts, as they think for themselves and explore with their students. Duckworth suggests that for this purpose we need accounts from teachers about "ways of opening up some part of the world to their students," accounts in which they explore and explain "how they went about engaging their students in the subject matter, what the students did, said, and thought, why the teachers did what they did, what they thought about what they did, what they would do another time" (Duckworth, 1987, p. xv)[1]. The three papers in this TERC Working Papers volume are contributions to this very important literature in the area of science teaching and learning.

Each of these teachers, Mary DiSchino, Laura Sylvan, and Chris Whitbeck, participated in a seminar for teachers as part of two projects funded by the National Science Foundation; these seminars constituted a four-year collaboration between teachers and researchers in which participants "did science" together by investigating their own scientific questions, experimented with new teaching practices, and explored in depth various instances of teaching and learning by studying videotape and transcripts from participants' classrooms.

Science is an intimidating discipline to many people, teachers and non-teachers alike. The language of science is authoritative and powerful. Many teachers worry that their students may not have a good experience in this domain. They are concerned that students may feel inadequate or "dumb" in science, that the knowledge which students bring to school may be overwhelmed or pushed underground by the science classroom which emphasizes quick answers and correct vocabulary. In response to such concerns, one primary goal of the teachers who are writing in this volume is that their practice should encourage students to draw upon their own resources and their own points of view. The understandings and the questions that students come with should be honored even as they make contact with the knowledge and approaches of science. In the three accounts, these teachers attempt to take seriously students' own questions and students' out-of-school approaches to explanation and theorizing at the same time as they bring them into contact with other perspectives. To do this, the teachers focus on talk, the talk that is a part of learning science and the talk their students use in order to make sense of science. They make use of video and audiotapes in order to go back over what was said in classroom events, to explore it for the intentions and ideas that were perhaps not fully understood at the time.

Mary DiSchino, who teaches 3rd and 4th graders, teaches a science curriculum which she organizes around questions her students ask about the world. In this paper she tells the story of her students' investigation of one question, "Why do bees sting and why do they die afterwards?" Laura Sylvan has searched for ways to introduce "authentic" discussion into her 7th and 8th grade science classroom, discussion in which students are both respectful and genuinely engaged. She presents here two discussions which she felt were particularly fruitful and explores what the students were saying and what she learned about them from their talk. Chris Whitbeck, who teaches middle-school science, describes an investigation he did with four students from his class on how bicycles work; he explores in his paper the deeper view he gained on how the students thought about bicycles and on what experiences influenced their thinking.

Mary, Laura, and Chris base the stories they tell here on what they were able to hear when they listened to audio or videotapes; much of this they did not really hear, or did not have the time to think about, in the actual moment. By taping conversations and going back to them later, the teachers are able to listen in a different way, speculatively and reflectively — I wonder what he means there, I wonder what she is referring to — rather than listening in order to respond right away as teachers usually must do. They are also able to pay attention to the contributions of students who may at the moment, and in the high activity of the classroom, appear to be off topic or not interested, or who are not saying what the teacher expects. Mary, Laura, and Chris, as experienced teachers, have intuitions and lore, tacit knowledge, which help them develop and reflect on their practice. But they are also challenged by the view of the classroom that they are able to have by means of the audio and videotapes; they discover some things they did not know about what their students think and how they are learning and participating, as well as how they themselves are teaching. Their experience of these events is deepened by the chance to go through them again. In addition, as members of their seminars, they are part of a structure of support for exploring the teaching of science. They are part of a conversation among colleagues, an important conversation based in data and reflection and support which we hope will grow to include many others.

Cynthia Ballenger, TERC

1. Duckworth, E. (1987). "The having of wonderful ideas" and other essays on teaching and learning. New York: Teachers College Press.

Teaching Science From the Inside Out

by Mary DiSchino

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Introduction

After twenty-four years of classroom teaching I am thrilled to say that I love to teach science! That the day would ever come when I could make such a statement is the ultimate tribute to successful staff development.

I teach 3rd and 4th grades in a public school where the students' backgrounds reflect the diversity of a city that has historically welcomed immigrants, from the Irish to the Portuguese to a current wave of people from Haiti, as well as long-term visitors from a multitude of nations who flock to two world-famous institutions of higher learning. It is an exciting, vibrant environment to work in. Creating an atmosphere of success in which all can share is my overriding goal; doing this in the area of science — which has such a powerful aura of inaccessibility — has been especially challenging.

Isn't science a field best left to experts and specialists? Isn't it too difficult to learn, never mind teach? Aren't we too ignorant — especially if we are women — to even consider the possibility of creating original curriculum for our classrooms? Shouldn't we, as teachers, simply do as the manuals tell us and try to straighten out our students' misconceptions before the end of each year?

The answer to all of the above is a resounding NO!

Four years ago my response would have been more along the lines of a "no." Lucky for me, I know better now! The reason for this new confidence stems from the work I have done in my classroom with the support of colleagues and researchers who are part of the Video Case Studies in Scientific Sense-Making Project at TERC, in Cambridge, Massachusetts.

In the fall of 1991, I joined with 12 teachers and science educators from several communities in the Boston area and educational researchers from TERC to work on a National Science Foundation grant that investigated the development of science education in the classroom while the teachers themselves engaged in learning science.

The first year of the project focused solely on teacher learning. We studied a local pond and attempted, in a variety of ways, to determine its "health." While proceeding with our inquiry and establishing a dialogue about our discoveries, seminars also gave us the opportunity to engage in various discussions regarding the teaching of science. Topics ranged from the need to "cover the curriculum" in order to prepare our students for the next grade and the inevitable achievement tests, to means of assessment beyond tests and quizzes. The conversations were provocative.

During the second year, participants were challenged to integrate new understandings into their classroom practice. How did our work at seminar influence our work in the classroom? Was our science teaching any different? We were offered the services of Video Cases Project staff to videotape two or three lessons on which we could get feedback from the group.

As our conversations in meetings progressed, I realized that I wanted to get back to creating science curriculum for my classroom based on the children's interests. It was something I thought I had done well while teaching primary grades but which I felt I had, since working with middle grade students, put on a "back burner," giving precedence to curriculum prescribed by manuals or kits. The school in which I work encourages staff to create their own curricula in all subject areas, but I had little confidence that I could create the rigor required of science learning at 3rd and 4th grade levels. As a result, I had focused on every subject but science.

The initial inspiration for attempting a change stemmed from work we had done at seminar with transcripts of a "science talk" that had taken place in a 1st grade classroom in Brookline, Massachusetts (Gallas, 1995). Reading the text carefully, together with project participants, I was reminded of the wonder, curiosity, and need to make sense of the world around them that students brought into our classrooms each day. Evident, too, was the fact that the children were keen observers who developed understandings of the world around them through their personal experiences. I wanted to tap into this wellspring once again.

Based on my own experiences as a learner (DiSchino, 1987) and the work we engaged in at seminar, I understood that learning science in a meaningful way involved more than doing a series of activities which led to an expected outcome. All the "hands on" lessons I could provide for my students would not necessarily contribute to their perceiving scientific questions from an inquisitive, open-minded, resolvable stance. I needed to create in my classroom the same atmosphere of questioning and collaboration of thinking among the participants that had been created for me as an adult learner. Did I dare put aside the guide books and the manuals? My involvement at TERC provided the opportunity and, more significantly, the support to try. I was encouraged to follow my instincts in developing the types of experiences that might help the children in my classroom develop the qualities I had come to value so highly.

Sherlock Time begins

I began my 1992-1993 science program with a talk about what science is and what "scientists do" when they work. The discussion proved very productive, as the children had much to say. Included in their remarks were ideas about: being curious and wanting to know the why or how of things, having an idea or "theory" that explained something, the significance of finding out that a theory was wrong, the amount of time it took scientists to get to an answer, the need for sharing data with others while keeping accurate records, and various ways of testing theories by creating models and experiments. Five critical tasks were identified and listed on a chart which remained posted in the meeting area of our room. It included the following key ideas: observe, gather information, experiment, interpret results, try again.

During our second session we brainstormed a variety of questions that we were curious about and wanted to pursue in the scientific ways we had enumerated the previous week. The questions the class came up with reflected the complex and confusing nature of things which were part of their day-to-day experiences: How can so many games fit on a Nintendo tape? What is a black hole? Why is there a sun and how does it shine? Why do we have hair? to cite a few examples. We established a 40-minute segment in our schedule when we would consider these questions, followed by a writing period to accommodate any writing we might need to do in conjunction with our discussions. Because this was to be a time of "investigation," we named it "Sherlock Time" — the children had come to know the famous detective through a book by Katherine Lasky which we had read at story time. Thus began our adventure of discovery. Every Thursday morning from 10:00 to 10:40 the "scientists" of Room 204 went to work!

Our first investigation focused on why days get shorter, a question that surfaced during morning meeting in late September. The class was talking about the changes taking place with the arrival of fall and I asked if anyone had noticed that it was getting dark much earlier than during the summer. Most of the students agreed they had noticed this phenomenon. I asked, "Why do you think?" We decided to talk about it during Sherlock Time. Because of my interest in the moon and its relationship to the earth, the subject of personal investigation since 1978 (DiSchino, 1987), I considered this a stroke of great luck. I felt it was a very comfortable and accessible exploration to conduct with the children.

From the very start I realized that I needed a tool to keep track of what took place during each discussion period. Because something new was created each time we met — there was no manual to look at, no list of objectives, no pre- or post-test to administer — a method of record keeping was crucial for gauging progress and determining how to proceed from one week to another. Since every moment of seminar was recorded, I had a new tolerance for seeing myself on video and I realized that videotaping each meeting in my own classroom was the most viable solution to this dilemma. Videos would supply an auditory and visual record of each session giving me concrete data to work with when preparing for subsequent discussions. I could spend my planning time looking and listening carefully to my students, instead of basing meetings on vague memories and impressions. The students' words and actions would act as the "manual" which suggested what best to do next.

Initially, the camera work was done by a student teacher, Julia Hendrix. Because of her unique perspective through the lens of the camera, Julia's focus was unique. The end of each session found Julia and me dying to talk to each other about what had just transpired. We quickly established a routine in which we would meet at the end of each taping day to discuss events and share insights. Together we explored possibilities for the next meeting, considering models, materials, and questions which might work to push our investigation forward. I would then take the video home to watch. The conversation with Julia informed my viewing, and together with my own interpretation of the events that unfolded before my eyes I would make decisions about what to do next. All of us — students, student teacher, teacher — were learning together.

Sadly, it came time for Julia to leave. Not only was there no one to videotape but, more importantly, there was no one with whom to share the excitement, doubts, and questions. I realized how significant this had been to the development of the work with the children. Thus I identified two components integral to working in this way: the need for a collegial relationship with a peer and the need for a detailed record of each session.

I was fortunate to be able to fill the need for a colleague with Lin Tucker, the science staff developer at our school. Lin attended our Sherlock Times, took notes, assisted, provided materials and resources, and met with me to discuss each session. This may very well be a different model for a teacher/staff developer relationship, but it is one which has worked successfully for both of us, each of us contributing different skills and talents.

My good fortune extended to the videotaping as well. A member of the Video Case Studies Project staff came in every week to record Sherlock Time. Once the project comes to an end, this support will need to come from elsewhere. I plan to solicit volunteers for the task — parents, student teachers, teaching assistants, school media center staff, members of the community — from wherever possible.

My students and I have since embarked on further inquiries that have addressed the questions: Where does ear wax come from? ("Another Set," 1995) How does food get to the tips of plants? Why is the sky black at night? What do we need to live? And, most recently, Why do bees sting and why do they die afterwards?

Each exploration developed its own unique personality. Children designed models to test hypotheses, used a variety of scientific tools to gain access to information, examined specimen, looked at diagrams and photographs, created models and displays to illustrate a point or test a theory, reflected on their own experiences, and talked, talked, talked.

Why do bees sting?:
Getting started

I would like to share in detail the most recent investigation which was conducted during the winter of 1995. I will present chronologically what the children and I did and comment on what I have come to see as significant.

The very first question listed on our chart for the academic year was, "Why do bees sting and why do they die afterwards?" It seemed an intriguing one on which to get the children's ideas and one I believed I could work with and was myself curious about. Thus, as in the past, we started our discussion on this topic with, "Let's find out what you think."

Whenever a new investigation began, this question provided a good way for the students to become engaged. It gave them the opportunity to articulate their thoughts and to share any knowledge they might have on the subject — without judgment of right or wrong — from their own personal experiences. During this initial talk, key data were often presented:

January 5

Dave: They have to protect the queen, they sting the enemy.

Akeem: They're attracted to moving things. People told me if you stand still, they won't sting you.

Arne: Bees sting to protect their food, to protect the honey. I agree with Akeem, I stood still [when a bee was flying around me] and it flew away.

Thus it was established that there was a queen bee who was so important that she needed to be protected, that bees risked their lives to safeguard this queen and to protect their food. And that, when not threatened, bees did not attack. Arne's reference to Akeem's remark was the start of connections made by the children of one another's experiences.

New possibilities for thinking were proposed:

Chris: The reason the queen lays so many eggs so fast in so little time, they don't need so many bees to stay alive long.

Robert: They use the stinger to get nectar from flowers to make honey.

Here Chris told us that the queen laid "many eggs" and suggested that the life span of bees might not be very long. Robert introduced us to flowers as the source of nectar, though mistakenly stating that the stinger was used to collect it.

I then asked the class to share any knowledge of bees they might have from personal experiences of being stung. I encouraged them to provide the details of that event while focusing on what had happened to the bee's stinger. More than three-fourths of the children had vivid accounts to share:

Shelly: The stinger had to be pulled out by my mom.

Kara: The stinger was right here [points to place on her arm]. I had to pull it out.

Thus it was verified that stingers were left behind when the bee attacked. More difficult to ascertain was whether or not death followed. No one had data that suggested this dire consequence for the bee although the students seemed to accept it without question. One student even speculated on a possible reason for the insect's death:

Lukas: I know why bees usually die, the stinger is connected to the heart.

Investigating together

My immediate response to this session was that the class needed a common experience on which to base further discussion. As a result, the meeting closed with the plan that Lin and I would try to procure stingers to examine for the next meeting. By the following Thursday Lin had found the necessary materials. In the period prior to Sherlock students examined the stingers under the microscopes. Lin adjusted her schedule so that she would be available to provide support for the children as they worked with slides, stingers, coverslips, and microscopes.

Now there was a basis for that day's conversation which allowed every member of the class to contribute. "Now that you've looked at a bee stinger, describe what you saw."

January 12

Elise got us started by stating that she "saw a black line that looked like a razor." She volunteered to go to the board and sketch it for us. This prompted several other volunteers to offer drawings of the stinger as it had appeared to them through the lens of the microscope. The class came to the consensus that the stinger was definitely not smooth. They agreed it was barbed, that the edges were jagged.

We then were able to talk about this characteristic as being the reason that stingers remained in the victim. Because some of the sketches showed the barbs pointing down and others showed them pointing up, we took time to speculate about the direction in which they would be most likely to point. In explaining why the barbs probably pointed downward, Yvonne commented that, "when the stinger is trying to go out, it would be hard." Akeem added, "It [the stinger] would go in like this [pointing with hands] but it wouldn't come out. The barbs would hook onto it [the skin]." Alex summed up the debate by stating, "It would make the stingers easy to go in but hard to come out!" Thus the consensus was established that Elise's sketch — which showed the marks pointing down — provided an accurate representation of the bee's stinger.

Nancy brought the conversation around to the consideration that the stinger contained a substance which could cause harm, and "a boy who got stung dozens of times. He died." This allowed others to contribute that some people were allergic to bee stings and that there was "venom" in the stinger which caused this reaction. Michael informed us that venom "is sort of like an acid." Dina further refined this definition by stating, "venom is poison." We took time to consider reasons the barbs might be poisonous.

Colleen, whose stepdad kept bees, told us that if the queen died, the hive died. Jackie added that the hive could not survive without the queen because she laid all the eggs. Here the children contributed diverse pieces of information garnered from various experiences, which enriched the dialogue and broadened the scope of the initial question. As the different "data" became articulated, the group as a whole created a new, more detailed concept of "bee." It was almost as if we were sharpening the focus of a photograph, slowly adding fine details not noticed at the first cursory glance.

When the clock told us it was time to end, the students were wondering out loud how a bee became a queen. This created the perfect lead into yet another session. As in prior investigations, the original question was creating more questions for us to consider.

Using texts

In the process of gathering information on bees, a colleague had given me a text that was so detailed it begged to not be read (Winston, 1987), but the illustration on the cover was fascinating! It told the story of an active hive with such conciseness and clarity that I decided to use it as the foundation for our next conversation. The drawing was enlarged, and copies were made for the students. (See Figure 1.)

Figure 1. Illustration by Elizabeth Carefoot from THE BIOLOGY OF THE HONEY BEE by Mark L. Winston. Copyright © 1987. Reprinted by permission of Harvard University Press.

January 19

At the start of Sherlock Time, the third meeting on bees, the children were given five minutes to peruse the sketch of the bee hive with encouragement to share insights among themselves. Our talk began with my asking each member of the class to say one thing they saw in the drawing. As they spoke, their observations were written down on a large chart. This is how the chart looked by the end of the session:

Diagram of Bee Hive

queen bee not yet hatched
it's folded up
it's enclosed
it's larger than the others
it's in a different part of the hive
it's in a part with a different shape
it's facing downward
it's away from other <u>larvae</u> —
    baby bee
    stage for insects
    like a worm — 1 of several stages
    egg — larva — — ? — — bee

2 bees together

1 bee coming out backwards
    bee with crossed wings
    bees with stuff on their legs — going towards the hive
    bunch of bees crowding around a large bee

1 in the middle is larger — could be
    cleaning the queen
    guarding the queen
    feeding the queen

bee feeding larvae (?)
    some of the combs are covered
    small, long, thin lines — eggs?
    worker bee
    queen bee
    drones

While accepting and recording the children's comments, I frequently reminded them to talk about what they could *see with their eyes.* They somesometimes gave interpretations, e.g., "Two bees are fighting." There was no way to determine if such were the case but it could be stated that, "Two bees are close together." I wanted the students to work with this distinction, one I believed critical at this stage of data gathering. Interpretation would come later when we used our conversations to piece together all the components of the "puzzle" created by our observations — the product of our *looking* and *describing.* Sometimes I pushed for clarification so that there would be common understanding of terminology among the participants in the dialogue:

Michael: It's (queen pupa) away from other larvae.

Teacher: What's a larva?

Dina: It's sort of like a bee that hasn't hatched.

Claude: It's bigger than the workers.

Colleen: It's an egg.

Teacher: Chicken have larvae?

Kara: It's a stage.

Dave: Bees have different stages. Larva is one of these — it's like a worm.

The discussion led the children to name the queen and the worker as two members of the community. I listed these on the chart and went on to inform the class that the workers, too, were female. I followed this with the query, "Would there be a need for another kind of bee in the hive?"

Dina responded with a question of her own, "Wouldn't the queen need to mate?" This gave me the opportunity to introduce the term "drone." Drones were identified as the males in the hive whose job it was to mate with the queen.

This session proved particularly productive. By simply looking at the sketch carefully and articulating their observations, the class had started to create an intricate, multi-faceted representation of "bee(s)." The image was formed by 23 different sets of eyes providing meticulousness of detail difficult to achieve by a sole observer! The children used careful observation to construct this detailed portrait. The chart recorded their contributions and provided a point of reference for this sophisticated, new portrait of "bee."

The big gap, obvious on the chart, was the one missing stage of development. We had identified the egg, the larva, and the adult, but there was no term for the form that looked so much like a bee but was not yet "hatched." Here was the perfect focus for our next meeting.

At the start of our study Lin had brought in three resources — all picture books, from which I learned everything that I used in developing this work with the class. One of them had amazing photographs of bees in the four stages of development (Oxford, 1995). Giving the photos to the children seemed the logical thing to do next, but before getting to my agenda I had to make room for Mark's demonstration.

January 26

Back to the stinger

At home, Mark had prepared a model to illustrate why the stinger was left behind after it was used and why bees died as a result. He was anxious to share it with the class. Mark had stretched fabric across an embroidery hoop to represent the surface to be punctured and had attached an oval-shaped piece of cardboard, containing string, to the end of a fish hook to represent the bee and the stinger. When sharing the model with the class, Mark pointed to the tip of the hook to show that it was barbed and then he proceeded to stick the hook into the fabric. As he tried to pull out the "stinger," the innards of the cardboard "bee" tumbled out and the hook stayed securely stuck in the material, no matter how hard it was pulled!

After the demonstration I followed up on a bit of conversation that had been left hanging at the end of the previous session, "Based on what Mark has shown us, why would the queen bee's stinger be smooth?"

Alex explained, "I think the queen bee's stinger is smooth because if it were barbed, when she stings, it would get in and it wouldn't come out. And, as Mark just showed us, it would pull out some of the vital organs and there would be no queen and there (joined by other voices) wouldn't be any eggs."

With this remark, Alex brought together information that had been presented throughout prior meetings to explain something for which there had, as yet, been no explanation. Implicit in his words was the knowledge that the queen bee was the only bee to lay eggs, and that the hive could not survive without a constant replenishing of the population. Consequently, Akeem pointed out, "A queen can sting two times. It [the stinger] comes out!"

Mark's model validated the speculation that had taken place during our second session after students had looked at stingers under a microscope. Mark had thought about what had been said and took his thinking into a concrete realm by creating the model. The ideas that had been put forward were integrated and mirrored back in a representation that tested the hypothesis *and* proved it right! Alex referred to the model to explain his conclusion: the queen bee had to have a smooth stinger because she was so indispensable that adaptations had been made to safeguard her. It struck me that the children were getting to the core of some basic "big" questions — considering the relationship between form and function in nature.

Differences among bees and what they do

Pictures depicting the four stages of development were handed out for the children to view (Fischer-Nagel, 1986). As they prepared to comment, the students were asked to describe the photographs starting with the one of the egg. Reference was made to the chart from the previous week and to the empty space between "larva" and "bee." When the group was asked to compare the larva to the next picture, Claude contributed a very obvious but, as yet, unarticulated comparison. "It's bigger. It looks like a bee." Here was a crucial distinction. At this yet unnamed stage, the bee finally looked like a bee! Claude's remark prompted several students to say the word "pupa." Somehow, they were now able to make connections to earlier experiences in which they had heard the term.

Now, it was out there, "pupa." We took time to talk about the characteristics of bees at this stage of development and made comparisons to previous and future appearance. Left unanswered was the question of how the bees were differentiated. What caused an egg to develop into a queen or a worker or a drone?

The very next day, Lin brought us four caterpillars in a small cup — one of the combined grade 1-2 classrooms was studying butterflies, which had mated. Their eggs were now caterpillars which, although different from bees, could provide parallels in our understanding of how bees developed. The class observed the specimen through the following weeks as they changed into pupae and finally transformed into butterflies.

It was back to the picture books for me. It was time now, I thought, to focus on the bees as adults. I chose a diagram showing the three types of bees, drawn to scale, next to one another, and enlarged photographs of the queen, the worker, and the drone.

February 2

The next session began with a review of the information and the terms that had been used the previous week to name the various stages of growth: egg, larva, pupa, adult.

The students identified what happened during the pupa stage of the bee's development:

Jackie	The shape is changing.
Joshua	The eyes develop.
Dina	The wings grow.
Rita	Their bodies grow.

Chris once again augmented the conversation by stating that, "regular insects, in the adult state, have a head, abdomen, and thorax." He was corrected by Joshua who said, "Head, thorax and abdomen." This exchange caused me to ask, "What part of the bee would remain attached to the stinger?" To which Dina responded, "The abdomen."

First, we looked at the sketch of the three bees and compared them (Lecht, 1973).

Claude: It's [the queen] bigger than the drone and the worker.

Michael: The wings on the worker are a little smaller than the drone's.

Colleen: There's a little more — longer abdomen.

Kara: The worker bee's legs are sort of fatter than the queen's.

Akeem: The queen's abdomen is kind of pointy.

We followed up with the enlargements:

Luke: The drone's eyes are bigger than the queen's.

Alex: The drone has a furrier neck.

Claude: Drone is the only boy — all the males in the hive are called drones.

The children were making use of vocabulary (abdomen, drone, worker, queen, male, hive) that had been developed in prior sessions to articulate accurately their observations and to express what they had come to know. As they demonstrated fluency with these words, I introduced more. Luke's remark prompted me to mention "compound eyes." Time was taken to elaborate on this new term and to further inform the class about the three smaller eyes in the center of the bee's head, which were used to see color (students had noted them in the pictures of the pupated bees the week before).

Charting

Sometimes I felt an irrepressible need for a chart. This seemed to happen when a lot of data had accumulated in our conversations. I did not want us to lose track of the data and I also wanted them available to inform further discourse. It was definitely time to "chart." Following are the two we created that day in response to my remark, "Let's make charts about what each bee's job is in the hive."

Queen bee

- lays eggs
- largest bee in hive
- rules the colony — hive
- eyes smaller than the drone's
- mates with drone(s)
- smooth stinger
- she leaves the hive only once to mate
- longer abdomen
- lives up to five years
- lays up to 1,500 eggs per day

Drone — Male

- mates with queen
- only male in the colony
- has large eyes — compound
- has thicker legs than queen
- smaller than queen
- seems to have furrier neck

There was no way for me to predict, as I prepared for each new talk, *exactly* what would happen next. Looking at the videos of each week's class helped me solidify what had taken place while suggesting possibilities to pursue or points to clarify. In this session I had planned to chart the role(s) of each bee in the community but, as you can see, I ended up recording descriptions and other information which the photographs evoked from the children. I went right along and followed their lead and lost my focus. I did not want to plan so rigidly that I would not respond to the children's ideas. The pictures — models, materials, etc. — were used to provide the framework for what I thought should be addressed next. Being open and flexible, and willing to allow the children to direct, as unfolding events warranted, was an integral part of the planning.

I knew next to nothing about bees when these conversations began. Therefore, if something I found answered questions for me, I believed it would also work well for the kids. I looked for "stuff" I thought would move the discussions forward and expand knowledge of the subject. I learned right along with the children. Sometimes, I did not know enough. Students would point out things I had not considered; in the very first meeting Robert mentioned that the stinger was used to collect nectar, and I did not know if he was right or wrong. Noncommittal responses on my part were genuine. I did not shy away from telling the class that I did not know and needed to find out. We really were learning together!

In reviewing this work and also reflecting on prior investigations, some patterns have emerged. Conversations began with the "What do you think?" question and then proceeded to an activity or experience which provided the concrete basis for the next discussion, for example, looking at bee stingers under the microscope. After engaging in this activity, every member of the class was able to participate, no matter what their "reading level," "learning style," or "educational profile." This was deliberate on my part, as it allowed each child constructive entry into the conversation.

The follow-up meeting had two parts: first, "Tell me what you saw"; second, "How does what you saw affect your thinking (or theory)?" Frequently, this type of data-gathering session resulted in more questions. Each student had a "science journal" in which to keep notes and record pertinent information. These were used sporadically and provided another avenue of communication.

Often, in the third or fourth meeting on a particular topic, a chart would be created on which we would list things we had come to agree upon or understand. I seemed to need this to get a sense of where things stood and I believe it gave the students a concrete yardstick with which to gauge the growth of their knowledge of the subject matter. The charts provided a visible, public record of the development of the investigations.

February 9

I began this meeting by telling the group that while watching the video from the previous week, I realized that we had set out to do one thing and had ended up doing another. I pointed to the charts and explained what I meant. It was plain to see that we had stopped listing "jobs" of the bees and had ended up recording descriptions. I wanted to acknowledge that this work was difficult for me too, and I wanted the children to know that their efforts during Sherlock Time were highly valued by me — I took time to watch them on video each week!

The focus on "jobs" was based on my hope that by being clear about what each type of bee contributed to the subsistence of the hive, the children would be able to make connections between the bee's role in the community and its physical characteristics, thus justifying observations we had made along the way: e.g., worker bees carry pollen to the hive in baskets which are on their legs, the queen lays the eggs in the cells and fertilizes those that will become workers or queen, the queen bee's abdomen is long and pointed, drones mate with the queen, drones are larger than the workers though not quite as big as the queen. We went on to complete this "chart" by listing the tasks done by the workers.

We talked about the changes we had witnessed in the caterpillars Lin had brought in and described the pupa stage. Then we moved on to examine an empty hive Colleen's mom had brought courtesy of her stepdad. The 23 children were split into groups of five or six and given about ten minutes to examine the different layers of hive we had available. I thought this experience would provide more data with which to further develop our discussion. Sure enough, it worked! The data gathering session that followed produced lots of new information and some new terminology:

Teacher: Let's go around and tell me what you saw.

Nancy: The hole had...had, like, six sides.

Teacher: What can we call it?

Nancy: A cell...honeycomb.

Kit: The comb is stuck to the wood [frame] with honey — or it could be the wax — I'm not sure.

Teacher: Somehow the cells are stuck to the wood frame.

Luke: It looks like the holes are really deep.

Yvonne: The honeycomb kind of feels like macaroni.

Dina: It was really interesting — every single cell is pretty much the same size.

Robert: It smelled very good — yeah, like honey.

Kara: When we looked at ours, some cells were — like they had a covering, closed — and when we looked, we saw honey!

Michael: We found stuff, it was like pollen in the cell.

Teacher: Describe what you found.

Michael: It was like cornmeal

Claude: We saw honey.

Mark: It was like — there was, like — hmm — well, the pollen, or the stuff that we thought was pollen — when you put it together and you squished it up, it was sort of like wax and smelled like wax.

Of course, all of the above was recorded on a chart. When the term "pollen" was introduced to refer to the substance found in one of the cells, I forced the student, Michael, to describe it. The class did not yet have a definition for the term, and a consensus of understanding needed to be established: pollen — like cornmeal. Now other students who had observed stuff "like cornmeal" would know what was meant when the word "pollen" was used.

Reflecting on my role: the late sessions

February 16

The subsequent session began somewhat differently from others. I wanted to provide information on topics that had surfaced in our discussions but had not yet been addressed. Several terms emerged as needing further development and/or clarification: cell size, wax, pollen, honey. Also requiring expansion was the question of how bees became male or female.

With part of the hive in my hands, I told the class that although the cells appeared to be all the same size they actually were not, some were larger. This difference was evident to the queen and determined whether she would fertilize the egg, creating a worker — the smallest in size of all the bees — or not, in which case the egg would develop into a drone — larger than the worker, smaller than the queen. We reviewed the fact that the queen's cell, which was also fertilized, was found in a separate part of the hive and had a different shape altogether. I confirmed that the honeycomb was made of wax by giving the children photographs which showed the underside of the worker bee's body secreting wax and several bees forming a chain to pass wax along in the process of building cells for the hive. I went on to inform the children that, though somewhat difficult to see, the cells on the hive were tilted downward toward the back of the frame. Instead of telling them the reason, I asked them why they thought it might be so. Speculation led to the following exchange:

Alex: So that when the queen lays eggs, she doesn't have to get into some awkward position.

Mark: Sort of like Alex, if the worker bees were coming in and they were straight she'd sort of have to [motioning with his hands] have to do this, if they're sort of, hmm, like down, she'd, hmm, it would be easier access.

Teacher: What do bees produce?

Jackie: Honey.

Teacher: What kind of stuff is honey? Is it powder, solid?

Dave: Liquid.

Teacher: If the cells were not tilted downward what would happen to the honey?

Yvonne: It would fall out!

Teacher: The cells are tilted downward so the honey won't fall out. What do bees feed on in winter when there are no flowers?

Elise: Honey.

Teacher: The bees use the cells for storage to survive in winter.

Jackie: If they store all the honey in the cells for winter, what do they do in the summer and fall?

Chris: They still eat honey. There are still flowers in spring and summer.

Mark: Oh, that answers my question about...there were sealed off things [covered cells on the hive] over there and that must be the reason why they're sealed off.

When this meeting ended, I had some misgivings about its success. I felt it had been too top heavy with "information giving" on my part. Watching the video closely, I have developed a new understanding of what transpired. Indeed, much *was* presented to the group but all the work done in previous weeks had created the context in which the children could place this information. They were ready to hear *and* hold on to it. Thus, Mark's comment, "Oh, that answers..."

In addition to preparing photographs to address the issue of wax production, I had selected photographs that dealt with the question of how pollen got transported to the hive (Fischer-Nagel, 1986). They showed the worker bee's legs.

Teacher: Who can tell me what they see? Describe what this shows us.

Michael: The one on the right looks like something is on it. It looks like liquid.

Dina: It looks like a big bump.

Alex... If it could be opened then it could be like a storing place for the pollen.

Yvonne: It could be, like Alex said, like a sack.

Dave: Bread. It looks like a loaf of bread.

Arne: It looks like, kind of like fluff.

Mark: Looks like maple sap.

Teacher: Alex, repeat your description.

Alex: If you opened it up, it could sort of be a storing place to carry the pollen it gets from flowers.

Teacher: How many remember talking about the legs of the worker bees compared to the legs of the drone and the queen?

Joshua: They were bigger.

Teacher: This is a picture of the legs of the worker bee. It has a storage place in which it carries the stuff it picks up in flowers. Can anyone describe pollen?

Luke: Pollen — orange and yellow...

Nancy: It's kind of like dust and it's yellow.

Alex: It's a kind of nectar.

Teacher: No, I don't think so. Nancy said it was like dust. See the hairs. They help push the pollen into the sack.

Here, I said the word "no." I did not accept Alex's suggestion in a noncommittal fashion but decided to negate his remark. There had been enough discussion to create the context for accurate information, even if it contradicted previous speculation, and I believed the time had come to be clear. The pollen baskets on the worker's legs were used to carry pollen. It was also interesting to note Luke's and Nancy's description of pollen which certainly reflected the definition that had been formulated in the previous session.

Perhaps clarification was a general characteristic of our discussion, which was the seventh on bees, at this stage. I believed the students were ready to hear *and* understand information that added to their knowledge of the subject.

Teacher: What is the other thing that bees gather from flowers?

Robert: Nectar.

Teacher: What is nectar?

Claude: Yeah, what is it?

Lukas: A sort of pollen but...

Teacher: Is it a powder?

Lukas: No, it's sort of gooey.

Teacher: Can anyone else describe nectar?

Claude: It's something liquid. It comes from the flower.

Teacher: What does the bee use to collect it from the flower? What does the bee use to get the nectar from the center of flowers?

Rita: Its legs?

Luke: Legs could carry the liquid, too.

Teacher: So you think the legs could carry the liquid, too?

Dina: I don't know.

Jackie: On its wings.

Akeem: Maybe its legs are filled.

Dina: Tongue.

Teacher: What might it do with its tongue?

Rita: Maybe on its back.

Alex: Last time, I remember we looked at those pictures of drone, worker, and queen, we talked about how furry their necks were. So I think that maybe the fur on the leg is for the pollen, and nectar collects on it there [the fur on its neck, (tapping the back of his neck)].

Teacher: That's a good thought. Mark.

Mark: I agree with Dina. You know how butterflies get nectar with their proboscis. I think bees might...

Teacher: That's sort of a fancy word. Want to say it again?

Mark: Proboscis.

Teacher: What is it?

Mark: It's sort...it's sort of like a tongue. They usually have it rolled up under their chin. You can see it on a butterfly — when they land on a flower they use it to extract nectar.

Teacher: Think of the pictures we looked at of the workers feeding the queen and the larvae. Does anyone remember how that happened? There was one picture that showed it. What were the workers feeding the larvae with? What were they sticking into the cells?

Michael: Their head.

Dina: Their tongue.

Fortunately, there was just the right picture to show the class at this point (Fischer-Nagel, 1986). After drawing parallels to other animals that feed their young from their mouths, the discussion came to a close.

I wondered how many had heard the new term "proboscis" and were brave enough to repeat it. Unlike butterflies, bees have a "straw-like" tongue with which to gather nectar. Yet I left Mark's suggestion unchallenged. To me, the significant points were that he reinforced the idea that a kind of tongue was used, he drew parallels to prior knowledge, and he connected his speculation to Dina's. As is evidenced in the closing line of the conversation, Dina was able to stick with her conjecture.

The transcription above is that day's conversation almost in its entirety. It is my hope that in reviewing it, the reader will get a clear sense of how these exchanges between students and teacher can develop. There is no one, right way, nor is there a way to guarantee success. It is also important to realize that our immediate response may not be an accurate assessment of what transpired. With time and careful scrutiny of the session I had thought unsuccessful, my opinion of the discussion underwent a complete turnaround. Viewing the tape carefully and transcribing the conversation told me that I had been wise to follow my instincts. It had been just fine to disseminate information because the class had been prepared to receive it.

Evaluation

March 2

We started the meeting by taking a look at all the different photographs we had used in our study. Looking at the pictures could remind the children what we had discussed. I then proceeded to go around the group giving each student time to state one thing s/he knew about bees.

Rita: Worker bee does all the things in the hive.

Shelly: [After much encouragement] Queen is the biggest.

Teacher: Which is the male?

Shelly: The drone.

Teacher: Is there another kind of bee?

Shelly: A worker.

Teacher: See all you knew?

Mark: I learned about wax glands and how they're used to build the honeycomb.

Kara: [Inaudible on video]

Claude: I learned that the queen is bigger than the others. The queen bee's job is bigger than the other jobs.

Teacher: What's the queen bee's job?

Claude: The queen bee's job is to lay the eggs.

Jackie: The drones get kicked out in winter. There's not enough food to share. They store all their food.

Luke: I learned that the worker bees are female.

Nancy: [Inaudible on video]

Teacher: What's the shape of the honeycomb?

Nancy: I learned that it's a hexagon and it's used for lots of things.

Teacher: What's one use?

Nancy: It's used to hatch the eggs.

Alex: The drone has the biggest eyes.

Cloe: I learned that the queen bee only goes out once.

Dave: Workers' legs are thick.

Yvonne: [Inaudible on video]

Lukas: I learned that the queen bee's got a smooth stinger.

Elise: Worker bees collect pollen for the hive.

Chris: Well, I learned three things. One, the queen bee's stinger is smooth and I also learned that there are different kinds of bees, and how they make wax with their glands.

Dina: There's only one queen in the hive and that bees have a tongue — to collect nectar from flowers [difficult to understand].

Arne: I didn't learn hardly anything.

Teacher: Do you need an eyebrow rub? [Secret code between us when Arne is feeling unhappy.]

Arne: No. I can't remember.

Teacher: Take a look at your pictures, they'll help you.

Arne: Babies look like little worms.

Teacjer: What are they called?

Arne: Larva.

Kit: Drones are the only males — they mate with the queen.

Robert: I learned about the pupa stage. They don't just go egg, larva, queen.

Teacher: What do they look like in that stage?

Robert: They look like a worm — no, like a bee.

Colleen: They have little pouches for carrying pollen

Michael: I learned that they have four stages: egg, larva, pupa, and bee.

I made everyone participate. I prodded and cajoled when necessary, but everybody had to say something because, indeed, everybody had something to say! I pushed the children further, "There are other things we talked about that people haven't mentioned yet." This added information regarding the shape and slant of the cells; the quantity of eggs laid by the queen each day; the fact that a bee died after stinging because it lost vital organs when the barbed stinger remained stuck in its victim; and bees using their stingers to protect themselves, the hive, or the queen. Dina even contributed that the queen bee's smooth stinger was used in fighting another queen bee to get control of the hive. This smoothness enabled her to pull the stinger out of her victim so that she could go on to "rule the hive."

The question remaining was what happened to make the egg in the odd-shaped cell into a queen? Chris reminded us that it was the size and placement of the cell that influenced what the queen would put in each — as had been presented in the previous session. I added that something else needed to happen. There was more to the equation than fertilized egg = female, worker or queen; unfertilized egg = male, drone. Arne said, "It depends on how they're [eggs] cared for."

Mark argued that it had to be more than just how the eggs were cared for because how we were cared for before birth did not affect whether we became male or female. "I don't think...when they... when they were still larvae...they're fed a certain way. It could be something sort of like that. Mostly the nutrients." This idea had been in the background whenever discussions led us in this direction and I was happy to address it. I introduced the term "royal jelly" and told the class it was fed to the queen egg throughout its development and to the other eggs only for the first three days. I went on to remind the class that the queen fertilized the eggs that developed into the females — both worker and queen.

The progression to considering why a queen might create another queen seemed quite natural.

Colleen: She might be dying.

Kit: She might not have room for her in her own hive but she might want her to go out and find her own.

Teacher: Why might she want another queen to go out?

Dave: If she died and there wasn't another queen the other bees would die.

Jackie: She mightn't know she laid another queen.

Teacher: Does the queen know if she's laying a queen?

Chris: It would know if she's laying another queen. It's the size.

I asked the children to consider what would happen to a hive as the queen went on laying up to 1,500 eggs a day. After Michael blurted out, "It would be too big!" (he restated his point and said that the *colony* would be too big, not the hive), we were able to think about the need for creating a new hive. Again, I found myself telling the children about the resident queen and followers "swarming" out of the hive in search of a new place to live, leaving the first of the new queens to emerge from its cell to kill those still in theirs.

We did not have a Sherlock Time the following week — there was a school event — but I was pretty sure that our investigation had come to an end because the class had no new questions even though there was much we had not discussed: life span, how nectar is transformed into honey, how hives survive in winter, and much more.

The librarian, who was by now intimate with our work, offered me the Reading Rainbow video on the honeybee ("Life Cycle," 1987). I was curious to see what would happen if the class viewed it, and I am so glad we took the time to do so! It was amazing to watch the children while it played. Their eyes and attention were *riveted* to the screen. I had never before seen them so focused on a video. Of course the program was excellent, but the attention the children lavished on the presentation spoke to more than just the quality of the production. They had a reason to watch. After eight weeks of thinking, talking, and wondering, the scenes that unfolded before their eyes played out what they had, up to now, only envisioned in their minds.

Looking back

The videotapes of each meeting gave me a wonderful record of the growth that had taken place, but I was the only one with the proof. I wanted to make this learning visible to others, including the children's families, who would not have the opportunity to watch six hours of "must-see" video. Needing another type of assessment tool, I remembered the infamous bee biology text (Winston, 1987) with too much information and thought about that wonderful illustration on its cover — the one we had used to create our first chart on bees. Why not use it again? I stapled it into each child's science journal and gave the class a chance to write about it.

Throughout our discussions I had had a number of concerns. Some children did not speak unless directly asked to contribute. Were they learning? Other students were newly mainstreamed from bilingual classrooms. Did they follow the development of the discourse? Several had difficulty behaving appropriately and at times were asked to leave. Did they grow in understanding of the topic? The journal entries revealed a broad range of development, typical of mixed age classrooms. Within this range there was evidence that each child had acquired knowledge which had been integrated well enough to be communicated through writing. Hindered as some were by learning disabilities, emotional difficulties, and/or limited English proficiency, every student wrote something that showed she or he had learned about bees.

In many instances, the entries in the journals addressed my concerns and removed them. Several of the students who had kept very low profiles during the conversations wrote in great detail about bees and their habits, establishing their total involvement during our meetings, despite their silence. Others, for whom integrating thought and writing was particularly challenging, made valiant efforts to pay close attention to content, language expression, and spelling, demonstrating their investment in both the assignment and the investigation. Also interesting were the entries of several of the most articulate participants. In two instances these students wrote straight out lists of terms which gave no hint of the richness of their thinking and the level of reflection which had been manifested throughout the discussions. Fortunately, the videos gave testament to the students' depth of involvement. Clearly, the structure of the task hindered some while it liberated others, making obvious to me that any one tool of assessment has its limitations. This experience has made me curious to think more about assessment. As with the bees, new data created new questions.

Final thoughts

No dazzling techniques were used to achieve learning. Our main sources of information were the children's personal experiences and knowledge, Mark's model, an empty bee hive, books, and a video. The majority of the time the children were seated in a circle on the rug — what is noteworthy is *how* the learning happened, *when* information was disseminated, and *what* the children were asked to do while sitting. Students were given the opportunity to make connections, to interpret, to listen to one another, to share experiences and prior knowledge, to revise their beliefs, and to create a whole new set of understandings.

An attempt earlier this year to create a productive exploration was not as successful. In that instance the question became one student's question. During discussions other children would express frustration saying, " But we answered your question already!," thus holding on to their own ideas, closing themselves off to new possibilities, and putting blame on the inquirer for not "getting it." I learned from this the importance of creating an atmosphere in which the group, as a whole, takes ownership of the inquiry. The *big mistake* had been in my wording — "Can anyone help ____________ understand?" Never again!

I'm not sure anymore that the question *has* to come from the children, e.g., Why do the days get shorter? The challenge is in making the question accessible — getting the children engaged in the investigation and curious to learn not only the "answer" but anything else that might be discovered on the way to it. In our bee study, the question was actually answered (though not confirmed) pretty early on — perhaps in the second session — but there were more questions that had been prompted by the very answer to that original question.

If the freedom to choose a topic is not an option, due to the need to follow a prescribed curriculum, I think similar discussions can be developed using the goals and objectives of a predesigned unit. As is evidenced in this bee investigation, the agenda emerged as new conversations took place. The initial question was not the only question answered. In retrospect, I realize that all of the following was "covered:"

1. There are different types of bees in a hive with different roles and different appearance.
2. Bees are adapted to be extremely efficient in carrying out their roles in the community; these adaptations are seen in their body shape and size.
3. The hive is a very ordered community which relies on worker bees for its survival.
4. Bees have four stages of development.
5. Sex of the bees is determined by queen.
6. Vocabulary
   queen, worker, drone
   egg, larva, pupa, adult
   fertilized egg, unfertilized egg
   compound eyes
   head, thorax, abdomen
   hexagonal cell, honeycomb, hive, wax
   pollen baskets, stinger
   pollen, nectar, honey, royal jelly
   barbed stinger, smooth stinger
   venom

At first, students did not know how to engage in the process of exploration. Early in the year, some responded with, "I don't know," when asked to give their thoughts. Learning to articulate an opinion and trusting that it would be accepted and given serious consideration, without ridicule, was a very significant part of what these children needed to know before they could become active participants in the dialogue. For many, theorizing out loud was a completely new and scary experience. As the year progressed, two of these children left their reticence behind and became significant contributors to the development of our investigations. A number of times their remarks provided the grist for lots of conversation.

There is no going back. This is what it means to me, now, to teach science.

Before leaving the classrom to work on this paper, I asked the children to use their words to try to explain Sherlock Time. I was curious to get their perspective. Since their voices have resonated throughout this effort, I think it most fitting that one of their voices should also bring it to a close.

Mark: Well, we kind of, like, try to get a logical answer for all our problems. Like, let's say, you know for this one [reference to question we had just been grappling with — How come the days get *longer* in the spring?], Chris and Joshua had two theories. I put both of their theories together and you got my theory and, hmm, so...you know, I think my theory's right [laughter in the background] but of course it's *my* theory...so, anyway, let's just say my theory is right. But, so, then, without Joshua or Chris' theories, you know, I would never have gotten that. So we take all the pieces of information that we get from all other sources and we put them together and, we, like, try to come up with a class answer.

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Getting Started with Science Talks

by Laura Sylvan

Introduction

I first experienced "science talks" in a 7th-8th grade Haitian bilingual classroom. The teacher of the bilingual class and I — a science teacher of grades 7 and 8 — were involved in a three-year National Science Foundation-funded project looking at "sense-making" in science as it was done by bilingual students. Part of trying to make sense of things was to sit together as a class and have students share their ideas and perceptions of what we had been studying. I realize now that what we were doing was not an earthshaking new educational technique; for years students have done this during "circle time" or "class meeting" in the younger grades, but I had never seen it applied formally to a middle-school science class.

My class that year was very quiet and only tentatively offered ideas. We were all feeling our way through science talks. Still I found the entire process appealing — it was a breath of fresh air to sit back in the circle and not be the focus of all interaction. I was intrigued with hearing the students' explain their ideas, yet I also had to engage in severe tongue-biting to keep myself from interrupting with answers to the problems the students posed. If I were always to step in with the final word, the students would never work on these problems themselves.

My excitement about science talks increased the next year when I was able to work in the Haitian bilingual classroom. Along with my original reasons for enjoying science talks the previous year, here was a class that was a lot more argumentative (in a good sense!). They challenged each other's ideas and observations. They were genuinely interested in what they were doing and at moments struggled to understand what they had observed during class labs.

At the same time, I continued to teach science in four monolingual classes (the majority of the students being native English speakers with several mainstreamed Haitian children also in each class). Although I pride myself on teaching "hands-on" science and doing many experiments and projects in my classes, I now found the level of discourse sadly lacking. I did not find these students as invested in any of the class talks as the bilingual students. There seemed to be more foolishness than any real thinking and a tendency for these students to pass over any deep thinking abut a question with glib comments. I began to wonder if the students in the monolingual class were capable of having an in-depth science talk.

During the 1993-94 school year I decided to make a commitment to doing science talks in my monolingual classes. I formalized the talks by giving assigned seats in a circle; students kept these seats for every talk. I pushed to do science talks at least once every two weeks. I often taped the talks and tried to transcribe parts of each talk. These transcriptions were read over in class, and we would comment on how well the talk went. On each student's report card I commented on their "ability to share ideas and listen to others" based on these talks and would also share insights with parents during conferences on how their child participated during these times.

I often used science talks as an introduction to what we were about to study. It was a good time to flesh out what students already knew or thought about the topic and to see some of the boundaries of their understanding. At times I would "prime the pump" by having students write a short paper on the chosen topic the night before the talk.

During that year my science talks often would remind me of riding a headstrong horse out onto the trail. I was never sure who was leading whom and what path we would finally take. At times I might have a strong idea about where things "needed to go" and at other times not much of an idea at all. There were excursions out when a pleasant time was had by all as we shared ideas together; there were other times when the journey felt wild, rambling, and just out of control. Then there were the best science talks when the students were excited and engaged and there was a tension; minds and ideas were being pushed and challenged. As Karen Gallas (1993) has stated, "When one child stretches his or her limits or logic and creative thinking, every child joins in and stretches." I would feel exhilarated, for some real science was going on. I was pleased to discover that, yes, all my classes could benefit from having a science talk!

I have gained many new perspectives about my students, their misconceptions, and their background knowledge; how they go about solving problems; and how they treat others in a discussion. Indeed, there were facets to their thinking that I would have missed under other class circumstances. For all the wild bumps and tossing abouts some of these talks took, I would not give them up in my classroom. I hope to incorporate them more in my teaching and work to smooth out some of the rougher edges.

Following are two transcripts that for me show science talks at their best. For each I offer my explanation of what I find in each student's contributions that make it satisfying for me.

"How do they do that?"

One dilemma I faced with science talks was introducing a good topic question to the class, one that would spark debate. One question that worked well was "Why are there so many different species?" I raised this question as we were studying classification. The question tied in with the current topic and also applied to the larger topic of evolution, which we planned to study at the end of the year. It is also important to note that this is a topic on which I felt well-grounded. Not that this would allow me to know all the answers, but I had the background knowledge to use in pushing the students to think more deeply about the topic. I agree with Ann Phillips (1990) when she states, "As my knowledge grew, my teaching improved.... The more dramatic change was that I began to learn how to ask fundamental, challenging questions of students." Still, there were times when students asked good questions that I was unsure how to answer, no matter how well I thought I knew the topic!

This particular science talk had not started out very well at all and was one of the more wild excursions out. After one student, Lynn, read her paper explaining why she thought there were so many species, I seemed to be seeing the worst in classroom conversation. Students were shouting out and interrupting, using the talk as a forum to attack a parent, laughing a lot and giggling, with no one really "on topic." There were a few glimmers of what I was looking for, but after 25 minutes they seemed few and far between. We were at the point of my challenging students to explain how the human species first appeared. I was not allowing the trite answer of "they evolved over time" to be mouthed by students — the process had to be explained more clearly, which led into the segment of the science talk presented here. After all the aggravation the group really focused and wrestled with the issue of a species adapting to its environment over time. I find it truly exciting when I am not lecturing the class but am in a real conversation, when I can really push the students to think about a topic.

Laura: Okay, let me just tell you a story, an example that somebody used, okay, this is a story when people were trying to explain why giraffes have long necks...

John: Yo...some dudes was like stretch....

Laura: ...why that's an adaptation they have so they can reach the tall leaves, okay... so the idea, James.... James, that's inappropriate, could you just keep that kind of conversation out of it...okay?

Edwin: Oh, yeah, cause they, cause they, have to get to the trees, way up high.

Laura: Alright, how did that happen because if...

John: Damn, right...

Laura: If they moved into an area and they had short necks and they walked into an area that was just all tall trees...

Joe: They'd get the helicopters.

Emil: Then, they, then

Edwin: They'd have to grow their necks.

Emil: No, no, no.

Laura: Okay, but they're going to grow their necks, are they going to grow their necks before they starve?

Emil: Laura, no, no, no.

Laura: Okay, Emil.

Emil: Edwin [someone screams], Edwin, if they jump, they'd learn to jump, after awhile

Laura: They would turn into kangaroos

Emil: after many years they'd learn to jump.

Laura: But that's not a giraffe.

Emil: I know. But he said they wouldn't jump, they would try and, would try and, like, reach with their necks and after awhile they'd just get longer and longer. And they, like, one time, they would have a baby with an extra bone, and then after awhile it would just be longer... more bones in the whole body.

James: Laura, Laura, I'm there, you were saying how they might get longer if they were, if there were tall trees and they were short, if they had short necks. They wouldn't, you wouldn't really need to adapt. You wouldn't need to be above the trees...You could feed below the trees, it doesn't matter. You only have to have your necks above the trees. No, I'm trying to say something. Shut up.

(Many students talk out.)

Laura: Okay, yeah, there's a reason why giraffes have long necks, right. They wouldn't have long necks for the fun of it.

Joe: Laura, Laura, Laura

James: I know that. I'm saying, if you, umm...(Sadruz: Maybe they want to see everything.)...if like, they wouldn't change if there were tall trees and they had, they had short necks...

Laura: They wouldn't change?

James: They might be shorter, but they wouldn't, they wouldn't.

Laura: So what would they be doing for food? They tend to eat leaves...

James: They'd eat leaves further down, not all leaves are at the top of the tree. They'd learn to climb trees.

This segment of talk starts with me introducing the often-used example of what could explain the giraffe's long neck. I give the example an extreme sense by having the short-necked giraffes "walk in an area" with tall trees to force the issue about the time needed for an adaptation to take place.

Edwin and Emil seize on the explanation Jean de Lamarck once provided of giraffes stretching their necks, thus allowing them to grow tall and then passing this trait on to their offspring. It falls into a trap that I and other students fall into at times: organisms willing changes on themselves. As Edwin states, "They'd have to grow their necks." Giraffes truly cannot decide to do this. For Emil to state in lines 35-42 that a baby giraffe is born with an extra bone in his neck is a valid mechanism of evolution if he had considered it as a strict mutation. However, at this point he is expressing it for the wrong reason by saying that it is due to the parent giraffes having stretched their necks so much.

James makes a very valid statement in lines 43-52. Why would the giraffes bother to adapt to the tall tree leaves anyway? They would just go on eating the grass lower down. The giraffes scenario I presented is somewhat artificial and creates this mix-up. A more realistic example would be if I presented the idea of an overpopulation of giraffes in a certain area and only a limited number of trees from which they could eat. How could the giraffes survive if only the topmost leaves were left for grazing? I largely ignore James's ideas at this point because I want the group to pursue the "adaptation over time" concept more. I am also trying to push on another basic premise of evolution — the characteristics that an organism gains from "external" forces, such as stretching, cannot be passed on unless they are "internalized" in the organism's DNA, most specifically the DNA of the sex cells. In the next sequence of talk, Emil and John will struggle mightily with this idea.

Joe: Laura, if there's, if there's food up there, I just can't say I'm going to grow my neck and eat that food.

Emil: No, you'd stretch your neck and then, after like a hundred years, then your babies are going to have longer necks.

James: You need more than a hundred years.

Emil: You'd go like this, right, you strain your neck...

James: Emil, it's more than 100 years.

Laura: Okay, let me, let me tell you a human example of this is that for thousands of years it was a tradition in China to bind the feet of young girls...

John: Yeah, the feet, the little girl's feet...they'd roll up that big.

James: That's nasty.

Laura: That was believed to be a beautiful characteristic so that they, when they were babies, they bound them, and they kept them from growing.

Edwin: Then they'd fall over cause they couldn't support themselves with their feet.

Laura: But, okay, so, every, every little girl born in China was getting her feet bound, but the next generation... so does that mean that...that they, girls in China, would start getting smaller and smaller feet every generation? (John: No, it's gotta be, it's gotta be...) Because in every generation they had their feet bound.

John: It's gotta be...it's gotta be...no, it has to be [pause] It's gotta be in, in, in, in, like, in your stomach, you know, like...you gotta, you gotta, do it...outside.

Emil: No, because it's not natural, it's not natural when it happened. It's not in your genes. (Laura: Okay) It's not in your traits.

Edwin: It's something that [inaudible] ...the age...

John: [inaudible]...giraffes...

Laura: It's a cultural thing, rather than a biological thing?

Emil: It's not something that they, that they needed.

Some of my biggest "trouble-makers" had a moment in this talk where I felt they honestly wrestled with some major problems of evolution. John is the one to focus on in this part of the talk. He is labeled as a learning-disabled student and has not been serious throughout most of the science talk, even within most of this transcript. However, I now see that although he was doing a lot of yelling out, much of it was oddly on topic. With line 101 he begins to struggle with why the trait of small feet is not acquired by Chinese girls whose mothers' feet were bound to make them small. Lines 104-108 are slowly spoken across 10 seconds, and I feel here John is really working with this concept. He never fully verbalizes it. In the next line Emil picks up on this idea and works on explaining it further.

Laura: Okay, but, okay but Joe's idea, I brought that up because you're saying that if you, or, urr, Emil was saying if you keep stretching that then the next generation, they might get that characteristic from you because you spent a lot of time stretching your neck, the young, your babies, are going to have a longer neck.

Joe: You're going to die.

Emil: You shouldn't be here either.

Laura: Yeah, well, that's this idea of time, is that if you're going to do your adaptation...you're adapting, Emil... (Emil: Hold up) ...how much time do you have to adapt before you die?

John: What's the kid [inaudible] say...Emil...

Joe: You have a whole tribe of monkeys let's say..

Laura: Alright

Emil: How do they do that?

Joe: All the fruits up there, but they can't climb the tree, right, a whole tribe of them. They're like all the same age.

Emil: They learn to climb the tree.

James: They'll learn to climb trees, they'll, like, make a ladder...

Emil: And they start teaching their children, right, when they're young, how to climb a tree...

Laura: Or, well, let's change, that's not something...

Joe: They'll die, they don't have any food, they can last, what, how long about...a month?

James: They can make a ladder...

Laura: So they die...so there's no longer...

James: They take some nails and a hammer...

Joe: They all die and they have little baby monkeys, right. The little baby monkeys may get, like, three days and then they die.

James: So why don't they, like, grab their parents...

Emil: No...

Joe: That's the end of all the monkeys!

Emil: No...they learn how to, they learn...

John: What kind of monkeys? JUNGLE MONKEYS!! (Laughter)

Emil: Joe, Joe, you don't know what you can do if you got hungry. Joe, you've never been hungry, right? These things are probably climbing up the trees you know, with their teeth or something like that...right. They teach their children how to climb the trees and that becomes instinct.

Laura: Okay, well, let's say, let's say it isn' something they can learn. Let's say, their arms are too short to go up the tree.

James: But they, like, their parents could, like, they could throw them up to the top of the tree and, like, grab the banana and come right back down and maybe they could have a banana for supper.

John: Banana...oh, na, na

Laura: So, alright...I think that's a really good point, so how are you as an organism going to change before you die, because Emil, Joe gave us a good example...

Emil, who earlier in the class was fooling so badly I had asked him to leave, has become very engaged at this point. He has earlier put forth a theory on how giraffes have developed long necks. He is challenged starting at line 70 by Joe and also James. I find these challenges interesting, especially on Joe's part. I feel Joe is closest to the right idea, and I am trying hard not to throw too much of my own support into his corner. I want to see how well he defends himself. At line 138 he begins explaining his idea on a monkey's fate if it is not adapted to its environment.

It is Emil's whole interaction in this that I find the most exciting. He is really into his viewpoint and determined to defend his theory. At line 134 Emil is being distracted by John, who wants him to start fooling around, but Emil says to "hold up" to John. This is truly a remarkable response for Emil, who often prefers to socialize with friends than to do classwork. He wants to hear my explanation and to stay on this topic. At line 141 Emil expressed his amazment. His "how do they do that?" seems to me to be an expression of honest bewilderment over how evolution occurs. Perhaps for the first time he has really thought and been puzzled by this. This one line expressed by a student kept me going throughout the year with science talks. These are powerful moments that stick in your memory.

Emil continues to stay engaged in his concern over Joe's story. He just does not want to see those monkeys die. Even at line 171 where John's disruptive comment sends many into laughter, Emil entirely ignores this so he can keep up his comments to Joe. Lines 173-180 are spoken with great urgency.

The concept of natural selection as it appears in this transcript is often labeled a difficult one for middle school students to master: i.e., the idea that an organism not well adapted to its environment will die. Emil does not present facts about ill-adapted monkeys dying off as Joe calmly does. He is having great emotional difficulty with the idea and earnestly searches for a way out, suggesting that these individuals might not die if they just tried hard enough. I am reminded that as a teacher I need to be aware of the emotions that can intricately tie in with the "facts" of evolution. For certain concepts they may form powerful forces against an understanding.

This five-minute segment contains many of the features that I find most appealing about science talks. I particularly value those times when we are really challenging each other's ideas as equals. I do not see myself speaking from "on high" in these talks. I perhaps have more information to share, but I try to avoid the role of being the one students should quickly turn to to get the right answer. My role is one of a "gatekeeper" to allow certain parts of the talk to go forward and to block others. I may comment at times and insert questions or scenarios to push the students' thoughts along. But just as actively I choose at times *not* to comment. The talk needs to go along on its own without my input, and I must work hard to recognize those moments.

"Well, I didn't actually see it happening, though"

This shorter piece of transcript comes from another kind of science talk. The task in this instance was to discuss the results of data we had collected in class. These talks seemed a little harder to get students invested in, perhaps because they were generally less open-ended. Such discussions are especially important to me because they are the dialogue, the back-and-forth sharing of information, that is a crucial aspect of science in the larger world.

In this situation I was preparing students for a larger study on population growth. With this project we would be charting the growth of a yeast population by counting the number of yeast in a sample population. The students would use a microscope to make observations and would study the population for nine days. I wanted the students to begin by setting up a lab involving one sample of yeast growing in plain water and another growing in corn syrup and water. Students were asked to prepare slides from each sample, observe them in the microscope, and make a drawing of what they saw.

The purpose of the science talk was for the students to report to each other what they had observed. From what we had done in class, we all had a common base of experience. One good part of this class discussion was that two students, Lee and Peter, both had their notebooks open and were referring to them as they spoke about the size of various yeast. Eileen and Ann did not have their notebooks to refer to but had strong recollections of their observations. Science talks allow class lab time to have greater validity because if students do not put the time and effort into their observations during the lab, they have less experience from which to talk.

I hoped students would comment in our discussion on how they had observed more yeast in the corn syrup/water sample. (With the corn syrup as a food source the yeast would show greater population growth and greater numbers.) I was surprised when Peter reported the yeast in the corn syrup/water were smaller than the others. I wanted to hear how the class would deal with his observations. The talk starts as Bryn, an MIT volunteer helping with this class, was asking how "those things," i.e., the yeast, could have gotten smaller, as Peter reported.

Bryn: What do you think...Guys, what do you think would have happened to make those things get smaller?

Eileen: Make what things get smaller?

Lee: (referring to notebook) No, they look bigger here.

Peter: They're smaller.

Eileen: They were the same size, there was just more of them.

Laura: Okay, so this is interesting. Peter is saying the...the ones with food were smaller and you're saying they were larger?

Ann: I think they were about the same size maybe...

Eileen: Yeah, Ann!

Peter: (refers to notebook)
And...and...and on the one without one they kinda have like dots inside and you can see dots but on this one you kinda like see a little bubble...kinda like a tiny, tiny bubble, clear.

Eileen: It could have been an air bubble.

Lee: Were you using the same power on both?

Peter: Yep.

Eileen: I, umm, Laura? I agree with what Ann said, that, um, like the cells, I think the cells were pretty much the same size...if anything, the ones with food were just, like, the teensiest bit bigger. But, umm, I thought the only change was that there were more cells in the one with food.

Ann: They were more clumped together.

Eileen: Yeah.

Bryn: How do you think they make more cells?

Eileen: How? They probably split.

Ann: It's probably the same thing as bacteria when they split, I mean, they...

Lee: Well, I didn't actually see it happening, though.

Eileen: Hey! Maybe that was what all the cells clumped together were!

Lee: Oh! Yeah, it could have been, like maybe they double and stuff and then just, like, split apart later.

Laura: Yeah, it's the thing that bacteria, we've talked about them a lot and never really got to see them in the microscope. The one good thing about yeast you can really, not well, but you can see them. And I guess I did want to share this picture with you. This was taken at (?: Ugggg!!) maybe over 1000 power magnification. This is a yeast cell, this is an organism, and on it you see these little circles forming, and what these are is, this is the beginning of, the cell's getting ready to reproduce. (?: Ohhh!) This is it...makes an extension off of its body. They call it a bud. And then finally it pops off.

Ann: ...starts popping off.

Andy: Yeah! That one up there!

Laura: Right here. I'm a little curious that, when you were saying they were smaller, I wonder if, 'cause when they first break off they actually are smaller.

Peter: Maybe when they have food they reproduce and then that's why... (Coughing)

Laura: ...there's more small ones in that situation.

Andy: How long does it take for the little ones to get as big as the big ones?

Laura: I don't know.

Bob: Why don't brain cells reproduce?

Laura: I don't know.

Peter: Wait! How long can the little ones put all their effort into...

Andy: When can this one reproduce?

Laura: I don't know how long it takes to kind of 'grow up'...and don't know how long it takes, if it does it every 20 minutes like bacteria do, or...

Sara: Oh! Oh! Like it's really short, not like a day, or five days, or a year, or something.

An important aspect of science talks is that they are one of the few opportunities for students to talk formally with each other. I am always interested in moments when the students directly refer to one another's ideas. There is a lot of cross-referencing in this short piece of transcript. Eileen is most formal in stating, "I agree with what Ann said" in lines 26-27. But as the students are engaged in helping to figure out how Peter could see what he was reporting, there are direct suggestions made to him by two other students. In line 22 Eileen explains that he could be seeing an air bubble, and in line 23 Lee checks whether he is using the same power of magnification. If we had not been having a science talk, I might have been the one to offer these suggestions, but, in this case, more engaged learning is taking place, since these suggestions are offered by the students themselves.

As a teacher I was happy to hear Ann refer to bacteria when she was responding to Bryn's question about how yeast reproduce; this was a science topic we had covered earlier in the year. Science talks provide good insight into which of the concepts taught earlier stick in the students' minds.

Lines 44-48 are especially exciting as Lee and Eileen wrestle with the idea of what the clumps of yeast are about. It is an "ah-ha" moment for them. For Lee in particular, a very bright student who was not always challenged by what we did in science, it was good to hear the excitement in her voice. I myself had to stop and think about their ideas at this point. Throughout the year's discussions there have been many moments where I was challenged by the students' ideas and questions. Because of this, I find myself taking time to research more on various topics and becoming a more active learner in the process!

I see my role in this science talk again as a gatekeeper to give gentle guidance to the conversation and to challenge and push students on what they have said (lines 10-12). At one point I introduced some basic information on yeast reproduction by showing them a picture in a book. When I introduce facts at these times I feel that they stick better, that there is a real hook in the students' minds because they are genuinely interested. The students' questions right after I explained the photograph show the continued interest; note in particular Andy's questions in lines 76-77 and in line 83.

I was happy to hear Sara's comments at the end of the segment. She had not spoken much until this point, but her statement at this time shows she was keeping up with the conversation. Her voice raises the issue of others in the class who were not heard at all.

Who's not talking?

As exciting as it is for me to hear six different voices discuss the topic of yeast, there were another six voices that throughout the rest of the time never genuinely entered into the discussion. I use the word "genuinely" because there are students who talk, but usually in a disruptive manner. Those student behaviors represent some of the ongoing issues of science talk for me, that is, both how to keep a sense of control and how to have more students invested in the talk and feeling accountable for what they say. There needs to be a certain looseness or there will not be a relaxed flow to the conversation. Some joking can occur, an offhand comment, a quick interaction, but these need to come and go quickly.

1 Charles: Are we gonna get our transcript?
2 Laura: I know I have been bad about
3 that, but I, I will work on it.
4 Dave: What's a transcript?
5 Bob: Do you hear that?! Let's have a
6 transcript.
7 Nathan: What we've said on the tape.

At times certain students would take control of the talk and carry it far from the topic at hand.

A comment like "okay, let's get back on track" or a specific statement addressed to a student, "and Libby, you're going to have to go back to where you were" could set the conversation straight, but at times the destructive elements force the conversation into such a start-and-stop setup that it breaks down altogether. One way I found to handle this is to deal with these students behind the scenes and to ask them privately, "Why do you need to interrupt?" or "Why don't you try to make positive contributions to our next talk?" I fell down at times on dealing with these students beforehand and behind the scenes and so was trapped into power struggles during the actual science talks.

Another group of students not heard were the quieter, shyer ones, especially the Haitian bilingual students most recently mainstreamed. Students who had been very vocal in the 5th-8th bilingual class now rarely spoke out. A few times I asked them about this, and they said they felt too shy and afraid to look stupid around the monolingual students. Other students would give their ideas only when directly called upon, and from their responses I could see they were involved in listening, but reticent to speak out. In some other cases when I listened to tapes of the talk, I could hear students comment in an offhand way ("Yeah, Ann") about the topic we were discussing. This showed me they were pretty well-involved in the conversation but never willing to state a public opinion to the group. Finally, there were students with soft voices who I would hear start to say something but be drowned out by louder voices. I need to see others in the circle be more aware of sharing turns and to listen for the markers of "umm" that mean someone else would like to join the conversation.

Continuing the journey

I plan to keep science talks an important part of my teaching. There are many positive aspects they bring to a class that I do not wish to lose: insights into my students' thinking and opportunities for students to challenge one another and try to solve problems among themselves. I need to work more on trust-building in the circle so that all students feel comfortable contributing and on better management for those few disruptive students. A place I would like to begin is just to share my insights with the students on "who is not talking" from this paper. I hope by my continuing to value these talks so highly, the students will also value them more.

Every other year in my class I require students to do a science fair project, which is another significant activity because it allows students to get involved in solving their own problems or questions through experimentation. I hope science talks can play an important role in getting students to think more deeply about their projects. I would like each student to share what she or he is doing in a talk and give the other students opportunities to comment and ask questions. This type of "peer review" — similar to what many scientists go through before beginning their research work — offers exciting possibilities for students to learn from each other ways to improve their own science projects. Science fair projects teamed with science talks — a challenging combination!

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"I Can't Think of it in Any Different Way": Addressing Children's Understanding of Bicycles

by Christopher Whitbeck

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Introduction

Over the past five years I have worked together with other teachers who are interested in how students make sense of science. We have wondered how students come to understand the subject matter that is presented to them and what aspects of teaching have the greatest impact on students' abilities to understand a science concept. We have worked to identify ways to structure lessons so that students are able to organize and share their thoughts about science problems. Our belief is that understanding how a child is thinking about a problem — allowing students to explain their thoughts — enables the teacher to identify when a child is thinking about a concept in the same way as the teacher and when their ways of thinking are contradictory.

Allowing each student to express his or her developing ideas is difficult when you are working with a class of twenty-five students. During the study described in this paper I worked with four students and tried to develop my abilities to listen and to understand how they were thinking about problems associated with bicycles. I worked with seventh grade students because in their science class they had not been formally introduced to the study of motion and its vocabulary: mass, force, momentum, work, fulcrum, etc. I knew that an investigation of bicycles often involves these concepts and was interested in whether the students use these terms and how the terms affect the way that they construct their understandings of a bicycle.

During the study I embraced the role of Teacher as Researcher. I presented initial questions and tried not only to understand how the students were answering them but also to understand why they were thinking about bicycles in the ways that they did. Although I did want the students to investigate certain aspects of bicycles, I did not impose an end-point. I presented materials and experiences that I thought might be useful based on how I understood the students' thinking. The study investigated students' abilities to apply theories developed on models to theories that stood up to a working bicycle. At times there was great frustration and difficulty as the students tried to apply their theories or as they tried to explain their thoughts to me.

Akia, one of the students with whom I worked, became the focus of my study. She would not accept explanations or ideas the way that many students might. She held tight to her beliefs and tried hard to explain how she was thinking about things. Akia was very honest and relied on her experience to make sense of science. She often gave answers based on feeling rather than science. Akia would say that a certain bike would be easier to ride up a hill because it "looked more comfortable" rather than comparing the size of the wheels. This manner of thinking was a talent that Akia possessed, but also a problem. Her steadfast hold to her beliefs and her need to relate ideas to her experience often made it difficult for Akia to see the possibilities of other students' ideas.

In trying to understand Akia and the other three students, I gained greater insight toward effective methods for teaching science concepts. Getting students to talk about their ideas so that I could understand them also engaged the group so that together they came to greater understandings. I believe that they learned more as a group then they would have working alone. They were able to build upon each other's ideas, and it became important to them to understand how each other was thinking about the bicycle problems. We did not come to conclusions about every question that arose, nor did I come to a perfect understanding of how each child thought about the bicycles. However, taking the time to learn how students combine their ideas to create a coherent theory of how things work was a valuable practice. It did not live only in the isolation of the study; it continues in my day-to-day interactions with all the students I see.

Getting started

I worked with four students: Nolan, Chris, Alison, and Akia. Each was in one of my two 7th grade science classes. The students were chosen randomly from a large number who volunteered to meet with me after school for one hour a week.

During our first meeting I explained that we would investigate a three-speed bike and that we would also have an opportunity to study the students' questions about how bicycles work. My intention was to begin a study of motion — perhaps focusing on why things move certain distances and why some gear settings on a bike require greater effort to turn the pedal. I hoped that the materials I supplied, and some of the initial discussion that came from my leading questions, would move us toward this topic. I was aware that the students might want to investigate questions that were not along the lines for which I prepared, and I planned to adjust for these investigations because they often yield important information. Ignoring these questions might have interfered with the students' thinking about other topics (they might have always wondered if their other ideas were really causing some reactions that we observed). I wanted them to have the opportunity to think through a problem in their own ways. I also wanted to improve my ability to understand the construction of their ideas; investigating their ideas instead of my imposed questions seemed to fit this goal.

Bicycle pictures

We began by drawing pictures that showed how a three-speed bicycle worked. Akia asked what a three-speed was. My first assumption had been identified — every kid knows what a three-speed bike is! Akia had a one-speed bike and had not had much experience with multiple-speed bikes. I did not ask Akia what "speeds" were. I wanted to give the students the opportunity to get their ideas on paper without my interruptions. There would be time for these interruptions later.

Chris, Alison, and Nolan began by drawing just the pedals and the gears. They explained that drawing the rest of the bicycle was confusing — it was difficult to connect all the bars that make up the frame. Akia was the only one to begin by drawing the front wheel and handlebars, and then to move to the pedals, chain, and gears. As the students drew, I asked them to annotate the drawing so that I would know how they thought all the parts worked. They all drew their bikes with two wheels separated by a pedal. Each connected the pedals to the back wheel with a chain. Akia connected the chain to the front wheel. As we discussed the drawings, she also connected it to the back wheels.

When I asked the students to explain their drawings, we made our first foray into vocabulary. Alison explained that the pedal was connected by a chain to a smaller disk on the back wheel. She called this smaller round disk on the wheel an "axle thing." I thought of this area as a gear, and I was glad that I had not said the word yet. If I had started talking about gears, I might have imposed my own vocabulary on this conversation. The students might have talked about gears instead of "axle things." Alison, Nolan, and Chris agreed to call this part an axle. Akia didn't say anything, but much later as I asked what questions they might have, Akia asked what an axle really was. For most of our discussion I took her silence to imply that she agreed with the other three students' explanation for axle. Apparently Akia was not working with the same definition: she wondered if the axle was an area or a real object. During our discussions I came to value the many questions Akia posed because they pushed us to investigate ideas that otherwise would have been taken for granted.

Chris, Alison, and Nolan all drew the back axle as having three different-sized disks. "There are three gears and they switch to different axles. The front pedal is not always larger but if the back axle is smaller, that makes it easier to pedal," Alison explained. When Alison refers to a pedal she is referring to the disk that the chain goes around, not the actual pedal that a foot pushes on. It was interesting to me that she used the word "gear." She seemed to talk about it separately from any of the different-sized axles. Nolan and Chris agreed with Alison that on the back wheel there were three different-sized "axle things," which had something to do with making the bike easier or more difficult to pedal.

I ended the session asking the students if they had any questions about bikes. Nolan wondered why the "axle things" got smaller. Chris wanted to explain how these different-sized things work. He wanted to move toward explanations several times. He seemed to value answers and told the students that having a larger axle in the back makes the chain tighter and this makes the pedal harder to turn. I still wondered about the difference between "axle things" and gears. Akia did not share any questions. I wondered what she was thinking.

Pedaling: pushing or pulling?

I began the second session questioning what made bicycles easier or more difficult to pedal. I had planned on using two pictures, one of an old fashioned "big-wheeled" bike and one of a modern bike, to discuss the difficulty of pedaling. I wanted to know which the students thought would be easier to pedal up a hill. I was prepared for them to talk about the size of the wheels or the size of the gears. Instead, the students decided that the most important aspect was that one bike pushed its rider and one bike pulled its rider.

"Which bike is going to be easier to pedal up the hill?" Chris immediately chose the modern bike because it had a chain that could be adjusted to fit with his loose chain theory from the week before. Alison chose the modern bike because, "If it wasn't better they wouldn't have made a new design." She quickly added that the rider on the modern bike would be turning the back wheel, which would push the rider up the hill, and the old-fashioned bike rider turned the front wheel, which pulled the rider up the hill. Although it did not seem important at the time, Alison's offhanded comment was about to involve us in a six-week study of push and pull.

Nolan began to wonder what type of motion the rider created when pedaling. "When you pedal, are you pushing yourself or pulling yourself? Because when you pedal, you push the pedal forward but you pull the wheel forward. It makes..." At this point Nolan began stumbling on his words. I believe that this was happening because what he was visualizing, the pedaling of a bicycle pedal, was not clearly pushing or pulling the back wheel. Nolan's understanding seemed tenuous, and as soon as he tried to explain it, he became confused.

Piaget (1974) wrote about a person understanding a solution to a problem, "Suddenly everything seems quite clear...but as soon as we try to explain to others what it is we have understood, difficulties come thick and fast." According to Piaget, this happens because the idea was connected to a schema of visual imagery, and this schema is incommunicable.

Nolan believed that the rider pushed the pedal, but in turn the chain that turned the back wheel did so by pulling that wheel. Was the rider really pushing or pulling on the back wheel? "When you're pedaling, would it *feel* like you were pushing or you're pulling?" Alison answered him by saying that it didn't feel like anything, "it just feels like you're pedaling." At this point the discussion no longer seemed to focus on words alone; there was a sensory image that accompanied what Nolan and Alison talked about. What they were saying was, "Once you understand the experience that I am talking about (pedaling a bike), what does it feel like? Does it feel like a push or a pull?" Those words, push and pull, bring with them an image that may be different for each individual, and these images are very difficult to communicate.

This investigation of images continued, and soon we were all discussing what the pedaling motion looked like. "When you're pedaling, your feet just go up and down," Alison said as she moved her hands on top of the table and her feet under the table. Chris made his hands go around in a circle (suggesting that your feet go around in a circle as you pedal), Akia pushed her hands in an up and down motion, and even I got caught up in trying to remember what it felt like to pedal a bike as I moved my hands up and down in imitation of the rhythm of pedaling. The students continued their discussion.

At one point I was so intent on listening to the students' conversation and the directions they had pedals and wheel moving that I had been quiet for a very long time. Alison said, "Are you still with us, Mr. Whitbeck? Have we lost you?" I assured Alison that I was still with them and listened for a little longer to their ideas. I finally asked if this pedaling motion was something that we could actually see if we tried it with a bike. The students agreed that we could and that arguing about it now was not that productive.

I led us back to pushing and pulling and what I thought would be a less sensory-based experience. I pointed to the pictures of the two bikes and asked if people thought that one bike was pushing and one bike was using a pulling motion. Nolan still discussed what it would feel like. Each of the students agreed that the old-fashioned bike was designed so that the front wheel pulled the back wheel and the modern bike was designed so that the back wheel pushed the front wheel. They also made it a point to say that neither of the two bikes was pushing or pulling its rider. The pushing or the pulling referred only to the relationship between the wheels. I then asked which bike would be easier to ride up a hill. All the students agreed that we would need to measure which was easier, pushing an object or pulling an object. (Although Akia believed that the modern bike would be easier because she was more used to that type of bike and the seat on the modern bike looked much more comfortable!) The students were agreeing to do this test next week only because I had brought up the push and pull question again. Although I was reluctant to make the suggestion because I did not want to decide what would happen each week, the students continued to be involved and enthused in the following weeks.

Measuring pushes and pulls

The next week I provided a ramp, different-sized and weighted round objects that could roll down the ramp, string, and several Newton spring scales. I explained that these objects could be used to test whether pushes were different from pulls but did not present an explanation of how I wanted the group to make the measurements. I didn't want to say, "This is a push and this is a pull and this is how you measure it." I believed I could get a better understanding of how the students were using the ideas of push and pull if I had them construct something that measured this concept.

They discussed how difficult it was going to be and tested many ideas. Chris worked at attaching the scale to the top of the ramp and tying the roller to the other end of the scale with a long piece of string. "When the roller comes to the end of the string, it will pull on the scale and we'll be able to measure how much it pulls on the scale."

Akia said that she did not understand how this was pulling. Nolan repeated her question. "The roller is just going to yank and then stop." Nolan was saying that there would be a quick pull and then nothing would happen. Akia began to explain to Nolan how it pulled (it was interesting that within seconds she was answering her own question), "The roller pulls on the scale." She did not see the "short-lived" pull that it would be making. Nolan easily gave up his idea and agreed that there would be a pull.

After several unsuccessful trials the roller went down the ramp and pulled on the scale, but it all happened so fast that the students were unable to make an accurate measurement. They were not pleased with this method of measurement.

Chris shared another idea. "If you let the roller roll down as you've said, you could let it push an object at the bottom of the ramp and measure how far the object went." He went on to say that it would not be as accurate as with a scale, but it might work. I asked him to show us what he meant, and he let the roller go all the way down the ramp where it ran into and pushed a second roller a certain distance.

The students were excited about this new measurement method, and we decided to test the pushing. After several trials (where Nolan carefully planned and Akia just wanted to try things), we were finally successful. The roller hit the second roller at the bottom of the ramp, and the second roller moved 38.7 inches. I was impressed at how carefully the students lined up the rollers and how carefully they measured before they ever formally tested. This took up most of their time but was very important to them. Again, had they not been careful in their preparations and had they gotten some weird results, they might have wondered if they had done something that had caused those results.

I tried to push the students to think about pulling. "Don't make us think about that yet, we're having enough problems with this," Nolan said. "We have to think about distance and making this work right and then we need to think about speed and that is all going to go into pulling." The students would remind me periodically that I couldn't move too quickly. I would need to slow down and think about the things that were confusing them.

The students continued to work with the roller pushing another roller at the end of the ramp. They got this second roller to be pushed 46.5 inches and 111 inches. I asked them what they had figured out. Akia suggested that she did not think that they were really measuring push. Nolan answered that the bicycle makes continuing pushing (actually the rider continually pushes on the pedals) but in our test case the roller only pushes once and is then stopped by the string. But he did not think that we had learned anything because we had not compared the pushes to the pulls.

I asked the students what they would know if they had information about how far the roller pushed and pulled. "If we did it the right way we would know if a push goes farther than a pull," Nolan answered. Here is my idea that they will accept results only if the information has been collected in the "right" way. "If you find that it pushes farther all of the time," I asked, "What could you say?" Nolan explained that, "If you push it, it goes farther with less work and that it would go farther if you push it once compared to pulling it once." I continued, "What could you then say about pushes or pulls?" I wanted to find out if they had other ideas that would not be addressed by the data that we were collecting. They agreed that they could say a push went farther than a pull. We ended the session, but no one said that a push was easier or required less work than a pull.

We're not measuring nothin'

Since it had taken two weeks to measure pushes, I did not want to spend a lot of time having the students figure out how to measure pulls during our fourth session. We had a lot of questions to investigate, and I felt as if we had not gotten very far. I spoke with Nolan during the day and planted some seeds about testing how far the rolling can would pull a stationary can. I asked him to present what we had discussed to the rest of the group, and when he did, the idea was quickly accepted. It may have been accepted because it had my approval, but I had not been successful in previous attempts to suggest a possible course of study. I believe that it was accepted because the students wanted to get on with the study, no one else had a better idea, and the idea had seemed to come from one of them.

The students placed a stationary roller on a long table behind the roller that would go down the ramp. There was a string attaching the two rollers, and as one of the rollers went down the ramp, the second roller was pulled by the first via a string. The string was long enough so that the second roller was not pulled until the first roller was at the bottom of the ramp (where it was stopped by one of the students). (See Figure 1.)

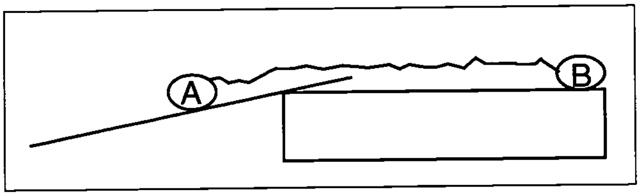

Figure 1. When roller A reaches the bottom of the ramp, it pulls roller B a certain distance.

"I don't understand how this is going to work. How is this going to be measuring a push?" Akia said as the students tied the rollers together. "Last time we measured a push, but we don't know if that really measured a push, we just know that it measured how far it stopped....We don't know if that's [the distance that the roller traveled after it had been pushed] a measurement of a push, we just know that it's how far the roller will roll." She brought this point up continually and never wavered in her insistence that we had not measured pushing or pulling. She seemed to have an incommunicable image of what a push was.

I asked Akia what the difference was between measuring a push and measuring how far the roller went before it stopped. "It's a lot of difference because measuring how far it goes is just measuring where it stops and measuring...I...I don't really understand what is measuring a push. Like, how do you measure a push?"

I asked Akia what made the roller on the floor move last week. She was quiet. "Some people would say that it was a push that made it move," I suggested, wanting to see if Akia would agree or not.

"I don't know. We are measuring it on a hill there (Akia was referring to the ramp), maybe it would be different if it were on a flat."

"What would be different?" I asked Akia.

"Because the ramp is giving it more speed."

"Are you thinking that a moving object pushes differently or doesn't push the same? Can you explain what you're thinking to me?" I replied. I was having a difficult time figuring out what Akia was thinking, and I wanted to take this opportunity to really understand why she did not believe that we were measuring a push.

"I'm thinking that a moving object is moving faster when it is going down than when it is going flat. When it is going down it has more of a push. 'Cause if you think about it, when you're riding a bike you go faster when you're going downhill than when you're going flat."

I believed that Akia was concerned with the fact that the roller was going down the ramp, and she believed that we were measuring something about the effects of the ramp rather than the roller's action on another object. She did not see the ramp as a control for speed that we used during both pushes and pulls. I asked, "If this roller is pushing on one object when it rolls down the ramp and it rolls down the same ramp but pulls on something, won't it be rolling with the same fastness?"

"Nope, it would be rolling quicker because it would be going down the hill." Akia was thinking of the ramp as a variable. She believed that we could only measure a push if we rolled an object across a flat horizontal surface.

I tried one more time, "But last week it was going down the hill also. Won't it be going at the same fastness?"

"Will it pull with the same fastness as it would push with? It will go faster because it's pulling," Akia answered. Wanting to know if she thought it was easier to pull than it was to push, I asked if she was thinking that a pull was different from a push.

"As we're doing it now it's kind of a pull and a push." She wasn't going to make a definitive statement. "The roller is pulling it, and the air is pushing it down." At this point Nolan entered the discussion. He had been listening to Akia and me talk about fastness. (I used this term because I did not want to be the one who brought up terms such as speed — fastness did not seem as technical, and the students seemed comfortable with its use.) Nolan said that the real difference was whether the object was being moved by a "jerk push" or a "steady push." A jerk push happens when the moving roller that is pushing hits the stationary roller, the moving roller stops, and the stationary roller is moved a certain distance. With a steady push, the moving roller does not stop, it continues its motion, and in so doing it continues to push the stationary roller. Nolan said that a bike would be a steady push because a person has to continually pedal (or push) in order to keep the bike moving. It was interesting to see an idea that Nolan mentioned the previous week carried over.

Alison added that she knew how far the stationary roller could be pushed by the moving roller that was traveling a given momentum. (I let momentum go by at this time, but I wanted to find out what she meant by it.) Now she wanted to see how far the same moving roller could pull the stationary roller when the moving roller was going with the same momentum. Alison seemed to believe that the ramp was controlling the "momentum" of the moving roller in both the push and pull test.

So far we had discussed the use of a ramp versus the use of the floor, push versus pulls, and jerk pushes versus steady pushes. Akia said that this made no sense! "Is this the way to measure pull and push, because I think that we are only measuring how far it goes." At this point Akia defined her confusion. She was not making a connection between the action of the moving roller and the action of the stationary roller. We could ignore ramps and all other things. For some reason she believed that all we were doing was measuring how far the object was moved. She did not believe that we could say anything about how it was moved or what was used to move it. *Why* did she think this way?

Akia ignored any relationship the students tried to provide as evidence. She was convinced that she was correct, her conviction was strong, and her understanding of push and pull were locked in an image that she could not communicate. She was not simply having difficulty describing her thoughts, she believed that she was right and did not feel the need to demonstrate her beliefs. Akia thought that her beliefs were being explained and that they should have been obvious to everyone. I was not sure if we should continue trying to change Akia's mind or if it was even possible at this point.

"We're measuring which one goes furthest with the same amount of work," Nolan tried to explain to Akia. I groaned to myself at Nolan's use of the term "work" and his insistance on changing her mind. I did not want to get into a discussion of what was meant by work. But as they had done before, the students questioned each other.

"How will we know that the same amount of work was done?" Akia asked. This was not the exact question I had in mind, but it had the same effect as asking Nolan what he meant by work.

"The same amount of time spent pulling as the same amount of time spent pushing," is what Nolan thought of as work. Akia was not sure of what he meant.

"What do you mean the same amount of time?" "They [the moving roller that went down the ramp] both stopped at the same time, and they both had traveled the same amount of distance before they pushed or pulled the thing. (The commonly accepted term would be that they were both moving at the same speed when they reached the end of the ramp — Nolan was thinking of this as work.) So we're measuring how far the stationary roller will go depending on how much it is pulled or pushed." Akia gave Nolan a questioning look and he continued, "Say you're riding a bicycle for two hours but one bike pushes and one pulls. If you go farther with the bicycle that's pushing for two hours than with the bicycle that was pulling for two hours, that is like what we're measuring. The same amount of effort has been put into pushing and pulling, but how far did you go for that effort. That's what we're measuring."

I felt comfortable with Nolan's explanations — I could not have said it better, and I was surprised by his connections to the bicycle. This relation to the bicycle was more coherent to me than his previous example. Even though some of his examples did not match perfectly, Nolan was able to move between the models that we were using and the bicycle's movements, something with which other students had difficulty.

"So then does it mean that the farther the object goes, does that mean that one is better than the other?" This was a question that Akia brought up again later — I was impressed that she continued to struggle with the same issues and was not just making up questions to be difficult. I asked her what she thought.

"I don't think that it means nothin'. I don't think that we're measuring anything. I don't think that it's measuring anything about pushes or pulls. I think that we're just measuring how far the roller goes."

Nolan was very frustrated with Akia. He moved around the room quickly and made large sweeping gestures with his hands, occasionally rubbing his forehead in frustration. He was not confrontational, but he got right in Akia's face and said, "Each moving roller spends the same time pushing or pulling. They stop and then they jerk," pulling on the string that was attached to one of the rollers. "By this we can estimate how far something could move if we pushed it for two hours."

"So, when the roller moves down the ramp, is it going to pull on the roller on the table?" Akia asked.

"It's going to jerk-pull."

"And we're going to measure it on the table? I still think that we're measuring nothing, but let's try it." And with that we decided to get to work. Akia's questions were still bothering me. I did not quite understand why she was having such a difficult time, but I thought it best to continue with the measurements.

The students tried trial after trial but continued to run into one problem: the stationary roller was always pulled a distance greater than the length of desks that they had for it to roll on. They had lined up three desks so that the roller could go approximately 156 inches, which was continually longer than the pushed stationary roller moved. When I asked the students if they could come to any conclusion from this measurement, they did not see the connection. They were stuck on the fact that the roller could still roll farther but kept rolling off the table; they never got to measure exactly how far it would roll.

After our last trial, during which the roller again rolled off the table, we put our materials away, and I asked the students to tell me what they had learned about pushes and pulls. Nolan began, "I think that we can't judge the two sets because we never measured how long the rolling roller pulled or pushed on the stationary object." Again, the issues of not doing the experiment exactly the right way and of time spent pushing or pulling were brought up. Nolan was concerned about variables and had tried to control every fine detail. I asked him if the slight difference in pulling or pushing time (fractions of a second) would cause the 45-inch difference that we measured between our pushing and pulling. He agreed that it probably would not but was unhappy that we had not controlled that well. The other students were not involved in this discussion at all.

Akia reiterated her question, "Are we measuring pushes and pulls?" I asked Alison if she had any ideas about this. "All this is showing is that the pulls went farther but I'd like to give the pulls and pushes a longer distance that they could possibly go." She was referring again to the short length of the table.

I finally said, "If we did everything right and we still got the same measurements, what could you say about pushes and pulls?"

"I couldn't say nothing because I still don't think that it's measuring a push and a pull. The numbers aren't even close." Akia held on to her position and also assumed that there would not be a large difference between a push and a pull. She continued, "Are the numbers…does the further it went mean that a pull is better?" But what Akia finally ended up with was that she could not make the connection between the pushing or pulling of the moving roller and the measurements of distance that we were making.

Akia's view of pushing and pulling

To give Akia the opportunity to explain how she thought we should measure pushes and pulls, I met with her alone during the next week. I hoped her explanation would help me to better understand her thinking about pushes and pulls.

I asked Akia to show me what she thought was happening. She had the two rollers on a flat table. There was no ramp. Akia said, "One roller goes into another and pushes it a distance….But a push is when it [the roller that moves down the ramp] keeps pushing it [the roller that the first roller runs into]." The important word was "keeps." Akia believed that we would only be measuring a push if the moving roller was allowed to continually push the stationary roller. She showed me what pushing was by placing one roller behind the second roller and pushing it along the table.

I took the two rollers and rolled one of them into the other. I stopped the one roller and the second roller continued rolling across the table. I said to Akia, "Some people would consider this a push also." Akia answered, "But that's a jerk push. And I think that we're only measuring how far a push is, not if one is easier than the other."

Akia believed that there were two different types of pushes, a push and a jerk push. I thought that this was the most important difference to Akia, but it wasn't. Akia was more concerned about measuring the *ease* of pushing and pulling. She didn't believe that measuring the distance that a roller went when it was pushed or pulled indicated how difficult it was to perform that push or pull. "I think we're measuring how far a push goes or how far a pull goes," Akia explained. "We don't know if going further means that it's better...if it's easier."

"What could we do to determine if something is easier to push or pull?" I asked.

"We could try pushing or pulling something ourselves that's very heavy. We could pull it and time how long it takes and we can push it and see how long it takes....We could see which one is faster... obviously the faster one would be the easier one."

I wondered if Akia was thinking about how much effort the person would be pushing or pulling with. "How would you know if you were pushing or pulling with the same amount of force?" As I said the word "force" I knew that I had used a vocabulary word that I had not wanted to introduce. Akia looked at me in a confused manner — she didn't know what I meant by force. I continued, "I don't mean force, I mean the effort." She continued to look confused. "What?" She asked. "How hard you're pushing or pulling...." I tried again.

Akia did not think that it would matter if one person was pushing harder on the object. "If you pulled something and it took a minute and two seconds and you pushed something and it took, like, 55 seconds, I think that pulling it you probably were pulling it harder than you were pushing it, so I think a push would probably be easier."

I asked about using the ramp. "Some people would say that the ramp is used to make sure that the moving roller pushes with the same fastness as it pulls with. It pulls on the roller as hard as it pushes on the roller." Akia agreed that the ramp would do this. "If this was the case, why would the can go farther when pulled?"

"Maybe it didn't go down the ramp with the same fastness," Akia answered.

This was something that I had never thought of and was what had caused the misunderstanding between Akia and me the previous week. Akia had a different idea of what the ramp was used for. She did not think of it as a control. When I suggested that the ramp was used as a control, she agreed that it could be but did not believe that in our case the moving roller always moved down the ramp with the same speed. "If it went at the same speed when it pushed and pulled, the pushed roller would obviously go about the same distance," Akia explained.

"What if you got different results?"

"If it went at the same speed, I don't think you could go a different distance." In Akia's understanding of what should happen, the stationary roller could only be pushed a different distance than it was pulled if the roller was moving at a different speed. She did not believe that the roller always went down the ramp with the same speed. The only way to address Akia's notion of pushes and pulls was to try her method.

Feeling a push and a pull

I was uncomfortable with Akia's disregard of the amount of effort that the pusher or puller would enact on the object being moved, but I decided to present this idea to the group, hoping that the other students would catch our oversight. However, they never mentioned the amount of effort with which a person pushes or pulls.

During this session I had a rolling cart that a person could sit on and be pushed or pulled down the school hallway. We attached a rope to the cart for pulling and one of the students stood behind the passenger and pushed on the passenger's back when we measured pushing. The students decided that I should be the passenger because I was the heaviest and would be the most difficult to move. They also decided that the same person should push and pull. We pushed the cart approximately five meters and averaged several trials for each method. We all agreed that the fastest method would be the easiest. It took 0.16 seconds less to push the cart than it did to pull the cart.

Nolan said that it was easier to start pushing than pulling. Alison thought that this had to do with being able to put your weight behind the object being pushed. She did not discuss using your weight to pull an object, although as I watched Alison try to pull me on the cart, she leaned forward with all of her weight and seemed to use her whole body to pull.

Alison was unhappy with the method of pulling and wanted to try tying the pulling rope around her waist so that the rope did not slip — this way pulling might not be so awkward. When we tested pulling again with the rope looped around Alison's waist, the pulling went much faster than the pushing — an average of 3.28 seconds compared to 3.94 for pushing, 0.66 seconds faster for the pull.

Akia explained that it was still easier to push than to pull because the first pushing time was faster. She did not understand Nolan's observation that a push was easier to start than a pull, and she ignored the second data set. Alison said that she was not sure that pulling was easier because the average values were so close. I reminded the students that during their last weeks of investigation they discovered that a pulled object traveled farther than a pushed object. I asked how they thought these two pieces of information were related.

Akia did not think that there was any relationship between the two tests. Alison thought that they should disregard the roller tests because they did not make sense. Nolan believed that there was some relationship but could not explain it. The students seemed very confused. I was disappointed with their abandonment of our previous week's work; it was unlike them to ignore the data.

Nolan asked Alison which felt easier to start, a push or a pull. Alison said that she wasn't sure which one was easier. In both, she described her action as just leaning forward and running. "You get momentum a lot faster," Alison said as she described me on the cart. "Momentum means that you get going and Mr. W could carry himself along if I let go. In the beginning of the push I could let go and he would have kept on going. In the pull I had to pull longer before this happened." Alison was unsure if this was the correct definition of momentum, but she believed that her description of me being able to keep myself going was correct. She related it to Nolan's original idea about it being more difficult to get an object going by pulling it. Once the object was moving it would carry itself, it was just harder to get it to this point using pulls.

I still wanted to know if they were thinking about our contradictory data. Our first test with the cart had pushes going faster than pulls, our second test reversed this, and our tests with the rollers had pulls going farther than pushes. I had an idea of the basis for their decisions. "Alison has talked about the 'feeling' of pushing and pulling. It feels easier to push than to pull. But our data show that it takes less time to pull than it does to push. Which do you think is easier, a push or a pull?" I asked.

Alison and Akia believed that pushing was easier. Alison chose to ignore the numbers and to rely on her personal experience. She believed that it "felt" easier to push than to pull. Akia had not ever tried pushing or pulling the cart, but she also believed that a push was easier than a pull. "In the beginning it was harder to start off pulling. If it was harder to start off, that means it was harder to do."

Nolan thought that "A pull might go faster than a push but a push might be easier than a pull." It seemed as though the students had chosen to ignore their original hypothesis that the method that travels a distance fastest is the easier method. They depended more on the feeling of the experience.

Just as the sensory aspects of pedaling a bike were important, the sensory aspects of pushing and pulling were also important.

So how did this relate to our original question about the bicycles? Assuming that the old-fashioned bike pulled its rider and the modern bike pushed its rider, which would be easier to ride up a hill? Alison immediately pointed out the differences. "Pedaling is different from running, and going up hill is different from going straight."

"But you still have to start off with a push and a pull," I countered.

"It doesn't matter, the push and the pull on the bicycle," answered Nolan. "A bicycle is different because the rider is always pushing."

"It only matters where the chain is attached," added Alison.

"But you've said before that the old-fashioned bike has the front tire pulling and the modern bike has the back tire pushing," I fought.

"But when we did the cart, the person pushing or pulling changed position. In the bike, the person was always in the same place. The only thing that is changing is where the chain is attached. In one experiment the person is the variable and in the bike experiment the chain is the variable," explained Alison. She thought that the chain never pushed, it only pulled.

Akia said that she didn't understand. Alison continued, "You know the pull would be the tire in the front and the push would be the tire in the back? Does the rider ever change their position?" Akia was still confused and Alison decided to draw a picture on the board.(See Figure 2.)

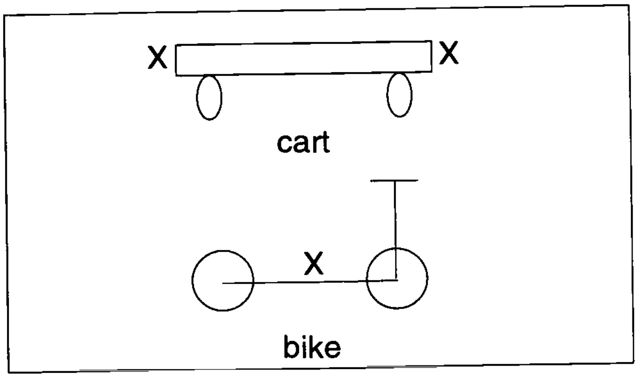

Figure 2. Alison drew a diagram to support her explanation.

The X represented Alison and she explained that she changed position during the cart, but on the bike she never changed position. Akia looked on, but was still puzzled.

Nolan continued, "The rope that we used to pull the cart acted like the chain on the bicycle."

"But the chain doesn't disappear when I push," answered Alison. She was referring to the fact that we took the rope off when we pushed the cart and she believed (as had Akia at the beginning of the sessions) that the chain on the bike was attached to both the back and the front wheel (this is not actually the case). "Also the chain can't push the wheel."

Nolan did not believe that where Alison stood had made much of a difference. He suggested that you could ignore the person on the bike. The back tire worked like a person pushing in the back and the front tire worked like a person pulling from the front of the bike. The cart and the bike were very similar. Everyone was silent....

"The front wheel still doesn't have to hold a rope." Alison said, referring to the rope she had to pull on to move the cart. The chain doesn't perform that function for the bike. I just disagree." Alison still did not think that there was a relationship, and she was having difficulty connecting this data to the bike. Once again, Alison had a specific understanding of how the bike worked. The rope and the moving person did not fit into that understanding.

I tried to move away from the bike and asked one more time, "Has what we've done told us anything about pushing or pulling?"

"I think it probably does but I'm not sure," said Akia. "I can't think of it in any different way."

Thinking about this in a different way was going to be important. Although our data were contradictory, the students had decided to ignore that; experience suggested that pushing was easier than pulling. It was difficult to transfer the experience with cans and carts to models of bicycles that did not clearly have a person standing in front of the bike pulling it or standing in back of the bike pushing it. I understood their ideas and also understood that they had reached a maximum point of mental discomfort. Their experiences did not mesh with their bicycle schema, and they could not think about the data in any different way. I asked them to think about all they had experienced and the following week we would begin discussing their understandings of the data.

During that week I continued to wonder why the students had ignored the data and gone with Alison's description of pushing and pulling. The data showed that pulling went farther and faster on two occasions, yet the students believed that pushing was easier. Were they having difficulty understanding what "easier" meant, was this a matter of believing numbers versus believing personal experience, or were references to the bike confusing the whole matter?

I organized the data into three charts. The first showed the roller and ramp trials — pulling moved a stationary roller farther. The second chart showed the first tests of pulling a person on a cart — the pushing went faster, and the third chart showed pulls going faster.

Akia looked at the data and said, "But Alison said that it was easier to push…wouldn't it be…I think our data is messed up. If pushing is easier than pulling, how come pulling went faster." Akia was not ignoring the numbers, the numbers did not agree with Alison's evaluation of pushing and pulling.

"If you just saw the data what would you say?" I asked.

"I would say that a pull goes faster and further. We would probably say that a pull is easier," Akia responded.

"But I think we have to think about facts and opinions," Nolan suggested. "I'd rather have a bike that was easier to pedal and I think that we left the subject of a bike too far behind." Although Nolan knew that the data could relate to a bike, he was having problems doing so. Even when I reminded Nolan of a scenario of the two bikes moving up a hill, he responded, "But I don't know how that would feel."

He continued, "Without the bike, I think a push is easier than a pull, a pull might be faster than a push, but I think that a push is easier than a pull." He could not demonstrate a pull going faster than a push, he saw the data, he said that he knew it was correct, but he had no idea why. He had decided to accept Alison's evaluation of push and pull. He supported his idea with the example that a modern bike pushes and that its design must be better. Nolan, as well as the other students, wanted to discuss why multiple-speed bikes are easier to pedal on some gears and more difficult on others. We ended our discussions of push and pull and pushed on to a new question.

So what happened? Why did the students decide that pushes were easier than pulls? I do not believe that it was an issue of ignoring the data, but rather that it was all wrapped up in images and feelings. Nolan could not relate the data to the feeling associated with pedaling a bike up a hill. For Alison too, the description of how it felt to push was more realistic than evaluating the numbers.

The students' images got in the way of comprehending several of the phenomena we studied. Nolan's difficulties with pedaling stemmed from the discordance between the motions of pushing on a pedal and the feeling of pulling the back tire. At one instance he understood those connections, but as he spoke, his ideas became muddled. He could not translate his image into words. The same difficulties occurred several times during Akia's interpretation of push and pull and the students' ultimate rejection of the collected data and acceptance of the feeling of pushing being easier than the feeling of pulling. This conclusion based on sensory experience conformed better to their images of everything involved with pushes and pulls. It was also easier for the students to rely on their feelings than to rely on data that were contradictory. It was very difficult to make sense of the numbers we collected, and it is not surprising that in the long run the students decided to ignore them.

These problems are present in the classroom as well. Difficulties in class arise when the teacher talks about one thing and students are thinking of a different experience. If they assimilate the teacher's examples or explanations into an experience that does not relate very well to their own, or if their image does not agree with conventional science and they assimilate the examples as supporting data, they leave with an incorrect understanding of the concept. Data collected in a science class are not always neat and easily interpreted. In an ideal world pushes and pulls should produce the same results on an object, but in this study they did not.

We are not near the end of our investigation, i.e., the bicycle works because of pushes and pulls, which means there will be continuing exploration of this phenomenon. I continue to think of experiences to address the understandings as well as the misconceptions of Akia, Alison, Nolan, and Chris. I am comfortable with our investigation to this point. It is important to remember that my overriding goal was to understand how the students were thinking about problems. I wanted to identify when the students were thinking about a concept in the same way as I, and when their ways of thinking were contradictory to mine. Akia provided wonderful practice with this, and my ability to understand how she was thinking about the bicycle improved a great deal.

For the students there were also positive aspects. They are thinking critically about bicycles and about ways of coming to decisions. In the long run I am not simply trying to increase the students' knowledge, I am providing them opportunities to invent, discover, and challenge the manner in which they think about things. I am hopeful this will have a longer-lasting effect than telling them that pushes and pulls are very similar — which they probably wouldn't believe anyway!

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